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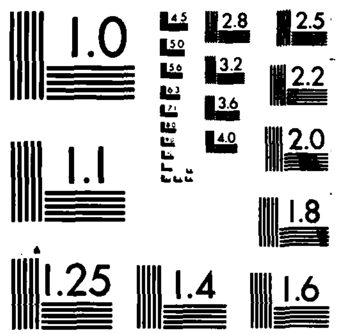

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ENHANCED EJECTION SEAT PERFORMANCE WITH VECTORED THRUST CAPABILITY

Lanny A. Jines
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Crew Escape & Subsystems Branch
Vehicle Equipment Division
Flight Dynamics Laboratory

August 1985

Final Report for Period 1 Mar 1982 to 1 Dec 1982

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This technical report has been reviewed and is approved for publication.

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The SAFEST Computer Program (~~AFWAL-TR~~-82-3013) and the EASIEST Computer Program (AFWAL-TR-80-3014) ~~are~~ were used ~~to conduct studies~~ to predict improved escape performance capabilities resulting from a vectored thrust control system.

A parametric study is identified and the results described to quantitatively establish enhanced performance envelope growth of the state-of-the-art ejection seat with an advanced controllable vectored thrust propulsion capability.

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FOREWORD

The Air Force Wright Aeronautical Laboratories (AFWAL) has an active technology program to improve the performance of manned ejection seat escape systems. The operational performance envelope of current ejection systems is deficient with respect to the operational flight envelope of current Air Force inventory aircraft. This report documents preliminary investigations directed toward expanding the performance capabilities of an ejection seat by incorporating control of the applied thrust vector upon the ejection seat.

This program was developed as part of an in-house effort conducted by personnel of the Crew Escape and Subsystems Branch (FIER), Vehicle Equipment Division (FIE) Flight Dynamics Laboratory (FI), Air Force Wright Aeronautical Laboratories (AFWAL), Wright-Patterson Air Force Base, Ohio, under Project 2402, Vehicle Equipment Technology, Task 240203, "Aerospace Vehicle Recovery and Escape Subsystems," Work Unit 24020336, "Escape Concepts Synthesis."

The work reported herein was performed during the period 1 Mar 1982 to 1 Dec 1982 by the authors Mr Lanny A. Jines and Mr Edward O. Roberts. The report was released by the authors in September 1983.

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SECTION I
INTRODUCTION

1. BACKGROUND

The operational performance envelope of current escape systems is deficient with respect to the operational flight envelope of current Air Force inventory aircraft. Figure 1 presents a typical comparison of a current technology fighter aircraft and the ACES-II escape system performance envelope which identifies the limited safe escape envelope. "Statistical analysis of crew survival data, following ejection from an aircraft, indicates a declining trend in survival rate and therefore establishes a critical need for advancement of emergency crew escape technology" (Reference 1). From 1949 through the end of 1980 the Air Force has recorded 4626 emergency ejections in non-combat operations (Table 1). Examination of the period from 1971 to 1975 yields a survival rate of 82%. However, the most recent period from 1976 through 1980 shows a significant decline for the survival rate (Figure 2). The survival rate of 75% for this period was a full 7% below the total average from 1949 and 2% below the previous worst 5 year average (1949-1953). Careful analysis of these statistical trends is contained in Reference 1 of this report. Detailed analysis of these statistics indicates that ejecting outside the escape system's capability (out-of-envelope) is the reason for the declining survival rate (Table 2). Of the 91 fatal ejections, 73% (66) were out of the envelope, either in the low altitude (61 cases) or high speed (5 cases) regimes. Identified by the analysis are three major factors:

(1) "the percentage of fatalities resulting from equipment failure is decreasing,

(2) the aircraft are being flown in unconventional flight maneuvers beyond the escape system's performance envelope, and

(3) the decision to eject is often being delayed until the aircraft is outside the escape system's low altitude capability."

The expansion of the ejection seat performance envelope in the low altitude adverse attitude escape environment represents a life saving benefit to the aircrews and Air Force mission.

The key to achieving increased survival rates during operational emergency escape is the development of an ejection seat flight control system in close association with increased and controllable propulsion energy. The control system would incorporate advanced state sensors, microprocessor(s), and controllable energy sources for selectable propulsive thrust. The tasks to be accomplished by the controller include: regulator control (i.e., elimination of seat rotational rates), variation of trim attitudes to control the direction of acceleration loads, guidance control (i.e., steering for terrain avoidance), timing of component operation, selection of active components and the selection of propulsive energies to suit the escape situation. This approach to improve escape performance represents an energy management concept which will allow positive modification of states during emergency escape to provide successful recovery of air crewmembers under the more severe flight maneuver environments anticipated for the next generation of aircraft.

2. SCOPE

Reference 1 (p. 31) identifies various parametric analyses which should be conducted to obtain a greater understanding of the behavior of an ejection seat during flight: "Sensitivity to weight variations, center of gravity variations, (c.g.) inertial properties, and temperature extremes must be evaluated. Timing, sink rate, roll, pitch and yaw rate effects must also be determined. Modified catapult performance, and variation of rocket thrust patterns as they influence the normal performance of the ejection seat, must be investigated." The effort documented by this report addresses some of the issues by computing the performance of both uncontrolled and controlled ejection seats with respect to trajectory and thrust requirements. The computer input parameters selected for variation are weight, pitch angle, roll angle, vertical velocity, altitude, rocket impulse, and the shape of the rocket thrust vs time curve. The computer output results were evaluated in terms of trajectory (altitude vs downrange distance), tail clearance, maximum achieved altitude, and ejection seat attitude at thrust vector rocket burnout.

SECTION II

SAFEST TRAJECTORY SIMULATION

In order to examine the effects of thrust and burn duration of different size rockets and to determine the impact on escape system trajectories, the SAFEST Computer Program was chosen as the simulation model. SAFEST is an acronym for Simulation and Analysis of In-Flight Escape System Techniques. SAFEST is a six-degree-of-freedom computer program that simulates an open ejection seat from the initial catapult ignition in the aircraft through parachute steady state recovery. SAFEST is the result of many years of technical effort and the specific details of its development and capabilities can be found in References 2 and 6.

The SAFEST simulation capability of the ACES-II ejection seat had been developed for a previous effort and, since it is the best available detailed representation of an advanced ejection seat, the decision was made to use it for this effort. The program data inputs were assembled and used which represent an ACES-II ejection seat configuration utilized in a close-air support attack aircraft.

The computer simulation requires an input data package of individual inputs of weight, and moments of inertia of each component that comprise the seat/occupant combination. The specific components used in this effort are listed below:

a) Pilot (5th or 95th percentile sizes)

b) Empty Seat

c) Rocket Propellant

d) Drogue Chute

e) Recovery Parachute

f) Survival Kit (empty, 26 lbs, 40 lbs)

Each of these components were measured individually or in various combinations to obtain their weight, c.g. position, three cardinal moments of inertia and three cross product moments of inertia as shown in Table 3.

Figure 4 is a plot showing the combined center of gravity positions for two dummy sizes and three survival kit configurations. Two live subjects were also measured in

the inertia facility for comparison with the dummy data. The results show a very close agreement between the two sets of data, especially the 5th percentile dummy and the small subject. The small subject weighed 142.2 lbs and the large subject 215.0 lbs.

The trajectory simulation using SAFEST was limited to three-degrees-of-freedom to simplify the analysis. The rotational motion of the seat was frozen and the seat was only allowed to vary in the three translational directions. By not allowing the seat to pitch, roll or yaw it assumes that the seat is completely stable, the rocket thrust vector is fixed in relation to the center of gravity, and the rocket energy is used to change translational motion only. The stability aspects of the seat are addressed in Section III and V.

SECTION III

EASIEST COMPUTER SIMULATION

1. COMPUTER PROGRAM

The EASY And SAFEST Integration for the Evaluation of Stability and Trajectory (EASIEST) computer program, documented in References 4, 5, and 6, was utilized to investigate ejection seat stability performance in which selected rocket thrust profiles were simulated. Reference 4 provides a brief overview of the EASIEST computer program with identification of its two major subprograms, the model generation program and analysis program. Additionally, example results are presented in Reference 4. References 5 and 6 represent the user's manual for the EASIEST program.

2. MODEL GENERATION FILE

The model generation program assembles a FORTRAN model of the escape system described by the user in the model description input file. The ejection seat model used during this investigation is the simulated ACES-II ejection seat modified to incorporate a simplified thrust vector control system. Appendix N of Reference 5 contains the complete model generation file of command statements and output diagrams for verification of the FORTRAN description (see pages 657 through 662). For the readers general understanding the escape system computer generated schematic diagram is provided in Figure 5 of this report. The alphabetic characters enclosed in the rectangular boxes identify modeled components of the ejection seat as well as the added components for a DART Stabilization System and an Aerodynamic Plate Stabilization System simulation.

3. ANALYSIS FILE

The analysis program is invoked following completion of the model generation program. The user supplies escape system input data and analysis directives in the analysis input file whereby the analysis program calls up the relocatable binaries from the model generation program, mates input files of data to the components, and executes the program producing the desired output data in numerical and printer plot form. Reference 5 Appendix N contains the initial analysis input file utilized for this study (see pages 663 through 665). The output is also shown in the same reference (page 666 through 675).

SECTION IV
TRAJECTORY/THRUST REQUIREMENTS ANALYSIS

1. TRAJECTORY CRITERIA

The analytical simulation was used to generate trajectory criteria for the design and analysis of future advanced ejection seat systems. The propulsion system and its specific thrust and time characteristics were varied to generate different trajectories to develop the criteria information. The following paragraphs contain this information which is certainly not all inclusive, but it is sufficient to develop trends and guidelines for a more detailed design analysis.

2. TAIL CLEARANCE

The SAFEST Computer Program was used to conduct a tail clearance trajectory analysis for various rocket thrust levels to show the impact on the seat/man trajectory. Figures 7, 8 and 9 are the tail clearance results for the three airspeeds of 250, 450, and 600 KEAS. As can be seen from these figures the aircraft velocity has a considerable affect on the tail clearance trajectory. For an airspeed up to 450 KEAS and an unaccelerated aircraft condition, the catapult energy alone is sufficient to clear the tail and provide a separation velocity between the seat and the aircraft. The 200 lb-sec to 1000 lb-sec impulse curves for the escape rocket are all for a 0.4 second burn time with constant thrust levels from 500 lbs to 2500 lbs. Except for the ACES-II case, the seat was not allowed to rotate and the thrust level was directed in an earth axis vertical direction. The configuration using a large subject (95%) and a heavy kit (40 lbs) was chosen for the simulation since it is considered the worst case. A lighter kit and smaller subject would yield higher trajectories. The relative position of a close-air support aircraft tail is shown in all three plots to demonstrate the different thrust level capabilities and the available clearance. The ACES-II trajectory is also shown on these plots to allow comparison with a current capability.

These plots can be used as criteria for developing minimum thrust requirements in the vertical axis for various airspeed when the ejection seat has a steering capability. As long as the steering rocket has a minimum thrust level in the vertical axis to clear the tail then the remaining energy can be used to provide terrain clearance and acceleration control.

3. INFLUENCE OF INERTIA

Table 4 is the result of varying the pitch axis inertia by plus or minus 10 percent of a 95th percentile seat/man combination. The pitch axis inertia was the only inertia modified since it is the only one which would influence a three degree pitch plane simulation. Of course, the rotational motion of the seat for these computer runs was allowed to vary with the applied forces. In the previous cases they were not allowed to vary. The analysis of Table 4 indicates that the influence of changing the inertia by 10 percent does not significantly affect the recovery altitude. Very little difference is shown over the applicable speed range. Therefore, small changes (+10%) in pitch inertia should not be considered a significant factor in the trajectory analysis.

4. DIVE ANGLE

Figure 10 shows the result of altitude required for various dive angles in plotting the data from Tables 5, 6, 7 and 8. Dive angle is the flight path angle below the horizon and angle of attack is zero. The only data presented are for the 95th percentile heavy kit configuration because it represents the worst case. The altitude required includes the time from catapult ignition to parachute recovery. These curves are strictly for the simulated ACES-II ejection seat and do not include any trajectory modification capability.

5. SINK RATE

Presented in Figure 11 is the altitude required for various aircraft sink rates at ejection for the ACES-II ejection seat. Sink rate is defined as the vertical component of the velocity vector with a zero angle-of-attack. The flight path angle is a result of the desired angle rate and total velocity vector. The 250 KEAS aircraft velocity is the nominal crossover condition for the change from Mode 1 and Mode 2 and this velocity was chosen to show the effect of sink rate. Again the 95th percentile-heavy kit condition was selected because it requires the most altitude for recovery. Figure 11 shows that the Mode 1 sequence has the better performance in the recovery attempt.

6. ROLL ANGLE PERFORMANCE

To investigate roll performance the six-degree-of-freedom simulation capability using SAFEST was used. Figure 12 is a plot of altitude required for various aircraft roll angles at ejection. Two velocity conditions are plotted, 0 and 250 KEAS, to

show how roll angle effects altitude required at both conditions. For the 0 KEAS cases the 5th percentile becomes the worst case for roll angles beyond 90 degrees. At 250 KEAS the difference between 5th and 95th is not as significant. These curves are again for the ACES-II ejection seat where the seat was allowed to rotate in a normal manner in all directions.

7. TERRAIN CLEARANCE

The next major trajectory problem after aircraft tail clearance is terrain clearance. Current escape systems do not have an intelligence or performance capability to conduct any maneuvering to minimize the loss in vertical altitude after ejection. A number of pilot losses in previous accidents have occurred where a few extra feet in altitude would have prevented a fatality. This section looks at terrain clearance for various escape rocket thrust levels and wings level aircraft dive angles at a zero-angle-of-attack.

Trajectories were run using SAFEST for the rocket thrust levels and burn time durations as shown in Tables 9 & 10. The two tables represent data at the two airspeeds of 200 and 450 KEAS. The thrust profiles were constant level thrusts over the specified time duration and they combine to yield impulses of 2000, 4000, 6000 and 8000 lb-sec. These impulses were chosen to represent realistic values that could be incorporated in an advanced escape propulsion system and yield trajectory data for a range of conditions. These tables present the altitude of the pilot at parachute recovery as a function of dive angles from 0 to 90 degrees. Some of the trajectories result in a required altitude below the initiation point and it is recorded as the number in the parenthesis. The negative numbers represent a recovery position at an altitude above the initial starting altitude at ejection. The rocket thrust application point on the seat was 8 inches below, directed upward near the nominal center-of-gravity. Since the seat was not allowed to rotate, this meant that the thrust was always directed in a vertical direction and it represents the ideal case in terms of trajectory modification.

Tables 9 and 10 also tabulate the results using the ACES-II rocket catapult also directed vertically through the center-of-gravity. Comparisons can be made in these tables to show the differences in thrust performance. Figure 13 and 14 are plots of the data from the Tables 9 and 10 for the 5000 lb and ACES-II data. For the constant

level thrust it can be seen that beyond a certain point in time a longer burn time does not affect the minimum point in the trajectory. For the 200 KEAS cases the 1.2 and 1.6 burn times do not provide any better performance than the 0.8 time. Since the vertical velocities are higher in the 450 KEAS cases it takes a considerably longer time to stop the sink velocity. Reducing the vertical velocity is the key to providing a maximum terrain clearance.

Figure 15 dramatically shows the effect of the longer burn times on the trajectory. The 0.6 second burn time provides a recovery point above the low point in the trajectory during rocket burn and, therefore, would be the optimum performarce for this particular case. The 0.8 second burn time does not influence the low point in the trajectory but it does yield a higher recovery altitude. This figure is only for one case and different velocities and dive angles would require either a higher or lower burn time.

By making a comparison between Tables 9 & 10 of the altitude requirements for the same impulse levels but different thrust profiles it can be seen that the higher thrust levels with the shorter burn time provide the better performance. The higher thrust levels initially reduce the vertical velocity faster which results in a lower required recovery altitude.

In providing for terrain clearance it would appear that the reduction in the vertical velocity with as high a level of vertical thrust as possible is the best solution. Human tolerance is a factor in determining the maximum thrust level and must be considered in providing the high thrust levels.

SECTION V

VECTORED THRUST ANALYSIS

1. APPROACH

For simulated ejection with a velocity of 800 fps and altitude of 900 feet mean sea level as initial conditions, the analysis conducted during this investigation involves the thrust vs time rocket curves tabulated as input in TABLE 11 and shown in Figure 16 through 59. There are forty four (44) thrust schedules consisting of the baseline case and forty three (43) subsequent variations. Each thrust curve was input into the EASIEST computer program Analysis File of input data utilized by both EASIEST ejection seat Model File (Model 1 and Model 2).

The Baseline Case, see Figure 20, represents a Talley CKU-5 "rocket catapult" sustainer thrust profile fired at a temperature of 74°F. This curve imparts 1031.4 lb_f-sec of impulse to the ACES-II ejection seat at that temperature. The Baseline Case as well as Cases 1 through 31, see Figure 20 through 47, all have a burning time of 0.350 seconds (350 milliseconds). Cases 1 through 16, Figures 17 through 32, were selected without concern for the amount of impulse imparted to the escape system. Note that among the baseline case and Cases 1 through 16, there occurs a coincidence: Case 5 and Case 12 of different thrust vs time curve shapes produce approximately the same total impulse of 1247.5 lb_f-sec and 1248.8 lb_f-sec respectively. Additionally, Cases 7 and 16 yielded approximately the same total impulse, i.e. 2182.5 lb_f-sec and 2183.8 lb_f-sec respectively. These thrust time schedules provide an initial investigation into establishing discernable effects of shape change upon the sustainer rocket driving a thrust vector theta-biased, pitch-rate feedback control system operating on the primary sustainer energy source of the ejection seat.

Cases 17 through 31, See Figures 33 through 47, retain the total burn time of .350 seconds but incorporate the three simple shapes of a rectangle (Figure 33 through 37), a triangle (Figures 38 through 42), and a combination rectangle with a triangle superimposed (Figures 43 through 47). These cases generate impulses of 1000, 1500, 2000, 2500, and 3000 lb_f-sec achievable by each shape. The maximum achieved thrust level varies among the cases in this series. For example, Case 17 (Figure 33), Case 22 (Figure 38) and Case 27 (Figure 43) all have different peak

thrusts of 2857 lb_f, 5715 lb_f, and 4214 lb_f respectively, however all three yield 1000 lb_f-sec of impulse. From Table 11 note that the TVC rocket burnout occurs at .566 seconds, into the simulation. This corresponds to a catapult ignition time of 0.001 seconds and the subsequent sustainer rocket ignition at 0.216 seconds.

The remaining simulation Cases 32 through 42 (Figure 48 through 58) and Case 43 (Figure 59) represent a departure from maintaining the 350 millisecond burn time of the rocket curves. The results of Cases 1 through 31 showed sufficient control capability for the TVC rocket thrust vs time curves yielding 2000 lb_f-sec and 2500 lb_f-sec impulses. Additional discussion of this result is contained in paragraph 2 of this section. As a result, Cases 32 through 36 (Figures 48 through 52) and Cases 37 through 43 (Figures 53 through 58) were executed to provide respectively, investigation of the same (2000 lb_f-sec and 2500 lb_f-sec) rocket impulse with extended burn time schedules. Note that Case 43 (Figure 58) provides 2500 lb_f-sec impulse over 1.6 seconds following ignition at .216 seconds. The resulting burnout time of 1.816 seconds into the trajectory simulation time corresponds to the preprogrammed recovery parachute line stretch event.

2. RESULTS

Table 11 contains the summarized computer results from the execution of Model 1 and Model 2 using the appropriate Analysis files incorporating the various thrust vs time curves for the simulated thrust vector control system.

For Model One (1) which incorporates the TVC, Aero Surfaces, and a Dart Stabilization system, Figure 60 contains the computed seat pitch angle at sustainer rocket burnout time plotted against the total TVC sustainer rocket impulse for the baseline case and Cases 1 through 16. Similarly the results for Model Two (2) are shown in Figure 61. The scatter of data points precludes reasonable interpretation of these results. Plotting the seat pitch angle 0 at time or rocket burnout for each similar shaped curve yields useful trend information. Figures 62, 63, and 64 for Model 1 and Figure 65, 66 and 67 for Model 2 display seat pitch angle vs impulse. Figure 68 and 69 presents the maximum trajectory altitude achieved in the baseline case and Cases 1 through 16 plotted against the total impulse, for Model 1 and Model 2 respectively. Figure 70 through 75 presents the same data but only cases of similar shaped thrust vs time curves appear on each figure (i.e., Figure 70 (Model 1)

and Figure 74 (Model 2) exhibits the results of Cases 5 through 10, and Figure 72 (Model 1) and Figure 75 (Model 2), displays the results of cases 11 through 16).

Closer examination of Figures 60, 61, 68 and 69 for the achieved results of Cases 5 and 12 as well as Cases 7 and 16 shows variation of seat pitch angles and maximum altitudes for each model (1 and 2) using approximately the same total impulse respectively. These results show initial dependence upon shape of the thrust vs time curve. Cases 17 through 31 were then added to the selected thrust vs time curves for a more in-depth investigation of performance results at given impulse levels but under different shape thrust profiles.

Table 11 continues with Cases 17 through 31 output results for Model 1 and Model 2. Figures 76 and 77 present seat pitch angle 0 in degrees for Models 1 and 2 respectively for this series of cases. Figures 78, 79, and 80 for Model 2 show the same results but plotted for similar shape curves respectively. Figures 84 (Model 1) and 85 (Model 2) present the maximum achieved altitudes for Cases 17 through 31. Figures 86, 87, and 88 for Model 1 and Figures 89, 90, and 91 for Model 2 show the altitude results for each individual thrust vs time curve shape. Reviewing Figures 76, 77, 84, and 85, the dependence of the pitch angle 0 and maximum altitude upon impulse is noted for the range of 2000 to 3000 lb_f-sec impulse.

The results of Cases 32 through 43 for both Model 1 and Model 2 are shown in Figures 92 through 95. This series of computer runs resulted from the performance sensitivity to thrust vs time curve shape previously shown for TVC rocket thrust impulses at 200 lb_f-sec and 2500 lb_f-sec. For this series of simulations the burning time of the TVC rocket was gradually increased, with thrust levels decreased appropriately, until a maximum burn time of 1.6 seconds was achieved. This burn time resulted in a trajectory rocket burn out at 1.816 seconds which corresponds to the typical recovery parachute line stretch event for the given initial conditions. For the extended burn time cases, Model 1 Case 32 achieved the best performance in terms of pitch 0 and maximum altitude for a 2000 lb_f-sec impulse. Case 32 achieved a pitch 0 of 8.4 degrees at rocket burn out which compares favorably with the initial 13.751 degrees pitch 0 at time of ejection. Correspondingly Model 1 Case 32 achieved the highest altitude for this series of Cases 32 through 35. For the 2500 lb_f-sec impulse thrust vs time curve Cases 37 through 43, Case 42 achieved the best pitch 0 of 6.2 degrees but it was Case 37 that resulted in the highest trajectory altitude of 80.60 feet where as case 42 achieved only 9.95 feet altitude (see Figures 92 and 93).

Evaluating Figures 94 and 95 for the 2000 lb_f-sec impulse cases using Model 2 we find Case 32 yielding the worst pitch 0 results of 34.3 degrees but the best altitude of 62.59 feet altitude. Among the higher impulse Cases 37 through 43, with 2500 lb_f-sec impulse, Case 37 has the second worse pitch 0 of 32.9 degrees yet achieves the best altitude of 90.02 feet as shown in Figure 95.

SECTION VI

CONCLUSIONS

1. TRAJECTORY/THRUST REQUIREMENTS ANALYSIS

From the simulation and limited analysis shown in Section IV some basic design factors can be outlined for an advanced ejection seat system.

First, current ACES-II catapult-only thrust levels are close to providing sufficient tail clearance for a major portion of the applicable aircraft velocities. A new catapult system which includes some provisions for limiting accelerations to stay within human tolerance need only provide a small increase in relative velocity between the seat and the aircraft to assure sufficient tail clearance under straight and level conditions. The specific design depends on the margin of clearance desired.

The sustainer rocket must be designed to provide an appropriate level of terrain clearance performance capability to optimize the trajectory within safe human tolerance limits. An advanced ejection seat will need conditious data such as the initial altitude, velocity, and sink rate to determine the specific course of action to take. Under some conditions of minimum terrain clearance, the rocket will have to be used to stop the vertical descent velocity regardless of human tolerance limits. This condition would require the maximum thrust available. The variability of the pilot size will contribute to the unknown maximum thrust application to stay within human tolerance unless some type of system is used to compensate for it. The difference in thrust levels between the 5th and 95th percentile subjects (to stay within human tolerance in the axis parallel to the spine) can be as high as 1200 lbs. This is currently 33% of the maximum thrust used on the ACES-II. The maximum thrust will also depend on the seat weight but it should be between 5,000 and 10,000 lbs.

Small changes in pitch inertia (+10%) did not significantly effect the trajectory results. However, inertia is an important factor in seat stability.

2. VECTORED THRUST ANALYSIS

From the simulation and analysis of 88 computer runs, all for a single set of initial conditions involving two models of ejection seat stabilization systems, the sensitivity to thrust vs time curve shape has been demonstrated with some basic design factors noted for future ejection seat systems. The use of sustainer rocket thrust for pitch attitude control enhances stabilization of the ejection seat at the expense of maximum altitude for a given thrust. When compared to an actual track test case of approximately the same initial conditions (759 fps for the test case vs 800 fps for the simulation cases) with the basic CKU-5A thrust time curve, the track test maximum altitude of 63 feet was measured, 24.78 feet computed for Model 2, and 18.00 feet computed for Model 1. See Table 4 of Reference 3, page 15 for HITECH program test data summary for test No. 49E-J1F. However, review of Table 2 output for Models 1 and 2 reveals that maximum altitudes in the range of 55 to 65 feet are obtainable with TVC achieving enhanced pitch control for TVC sustainer rocket thrust vs time curves yielding 60% to 100% increase above the 1031.4 lb_f-sec available with the basic CKU-5A non TVC sustainer rocket. Impulses in the range of 1600 to 2000 lb_f-sec delivered to the TVC rocket during the 350 millisecond intervals for Cases 1 through 31 resulted in maximum achieved thrust levels from 5000 lb_f to 10000 lb_f depending upon shape i.e., rectangular, triangular, combination rectangular-triangular. This noteworthy result compares favorably to the results of Section IV.

Attention to Table 11 Cases 3, 4, 9, 10, 20, 21, 25, 26, 30, and 31 involve impulses in the approximate range of 2500 to 3000 lb_f-sec. For these cases significantly increased maximum altitudes were achieved, i.e., Case 9 for Model 2 produced pitch of 13.5 degrees at rocket burn out with a maximum altitude of 122.98 feet. However Case 9 for Model 1 produced a pitch of 28.89 degrees, far from the desired initial ejection of 13.75 degrees, but still resulted in an altitude of 129.68 feet. Similar inconsistencies are noted among this group of identified cases.

Investigation of Cases 17 through 21, the rectangular shape curves and Cases 22 through 26, the triangular shape curves, reveal unexpected results of improved performance in terms of seat pitch and maximum altitude for the triangular shape curves over the rectangular shape curves. The slower onset rate of thrust with the triangular shape curves was expected to yield less control toward achieving desired seat pitch attitude and a resulting lower maximum altitude. This was not the case.

No immediate explanation is readily available from these analyses for results based upon only one set of initial conditions.

Complete use of these results for advanced design of escape systems is not recommended at this time. Additional parameter investigation to incorporate evaluation of thrust "build up" or "on set" rates along with shape sensitivity while measuring accelerations as additional performance indicators is necessary. Such analyses should be addressed for selected altitudes and velocity conditions to complete meaningful information useful to escape system designers.

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3. Lanny A. Jines, Computer Simulation of Ejection Seat Performance and Preliminary Correlation with Empirical Data, Flight Dynamics Laboratory, WPAFB, Ohio 45433, AFFDL-TR-79-3150, April 1980.

4. Lanny A. Jines, Christopher L. West, EASIEST Ejection Seat Stability and Control Analysis Capability, Proceeding 1981 SAFE Symposium, SAFE Association, Van Nuys, CA.

5. Christopher L. West, Brian R. Ummel, and Roger F. Yurczyk, Analysis of Ejection Seat Stability Using EASY Program, Vol. I, Flight Dynamics Laboratory, WPAFB, Ohio 45433, AFWAL-TR-80-3014, Volume I, September 1980.

6. Christopher L. West, Brian R. Ummel, and Roger F. Yurczyk, Analysis of Ejection Seat Stability Using EASY Program, Vol. II, Flight Dynamics Laboratory, WPAFB, Ohio 45433, AFWAL-TR-80-3014, Volume II, September 1980.

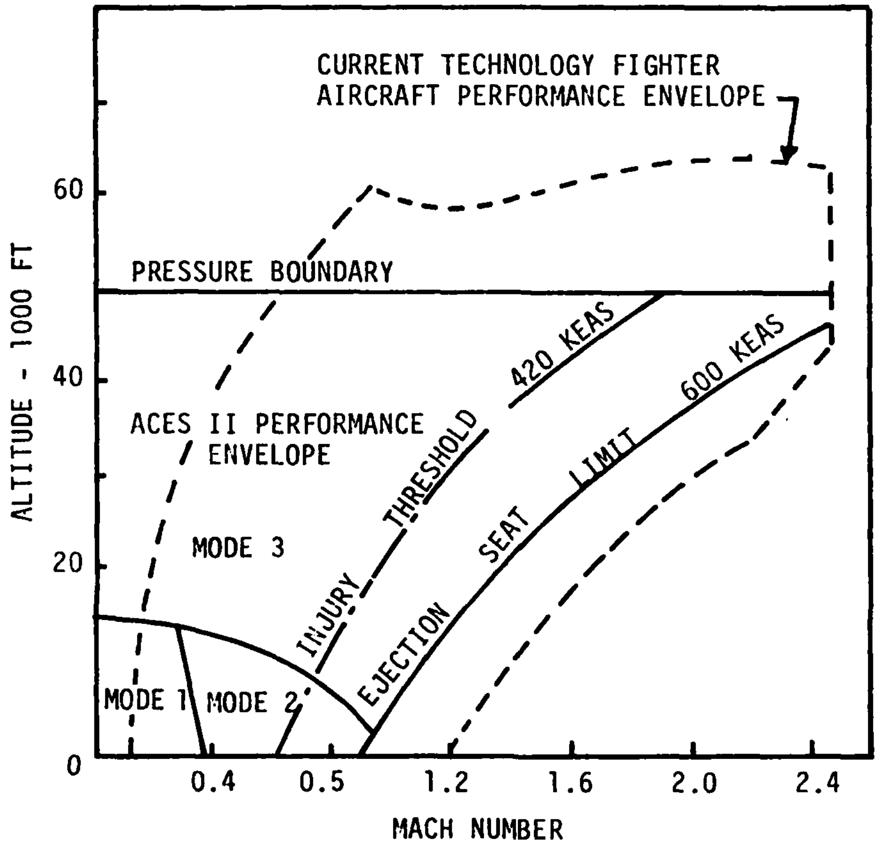


Figure 1. ACES-II Ejection Seat Performance Capability

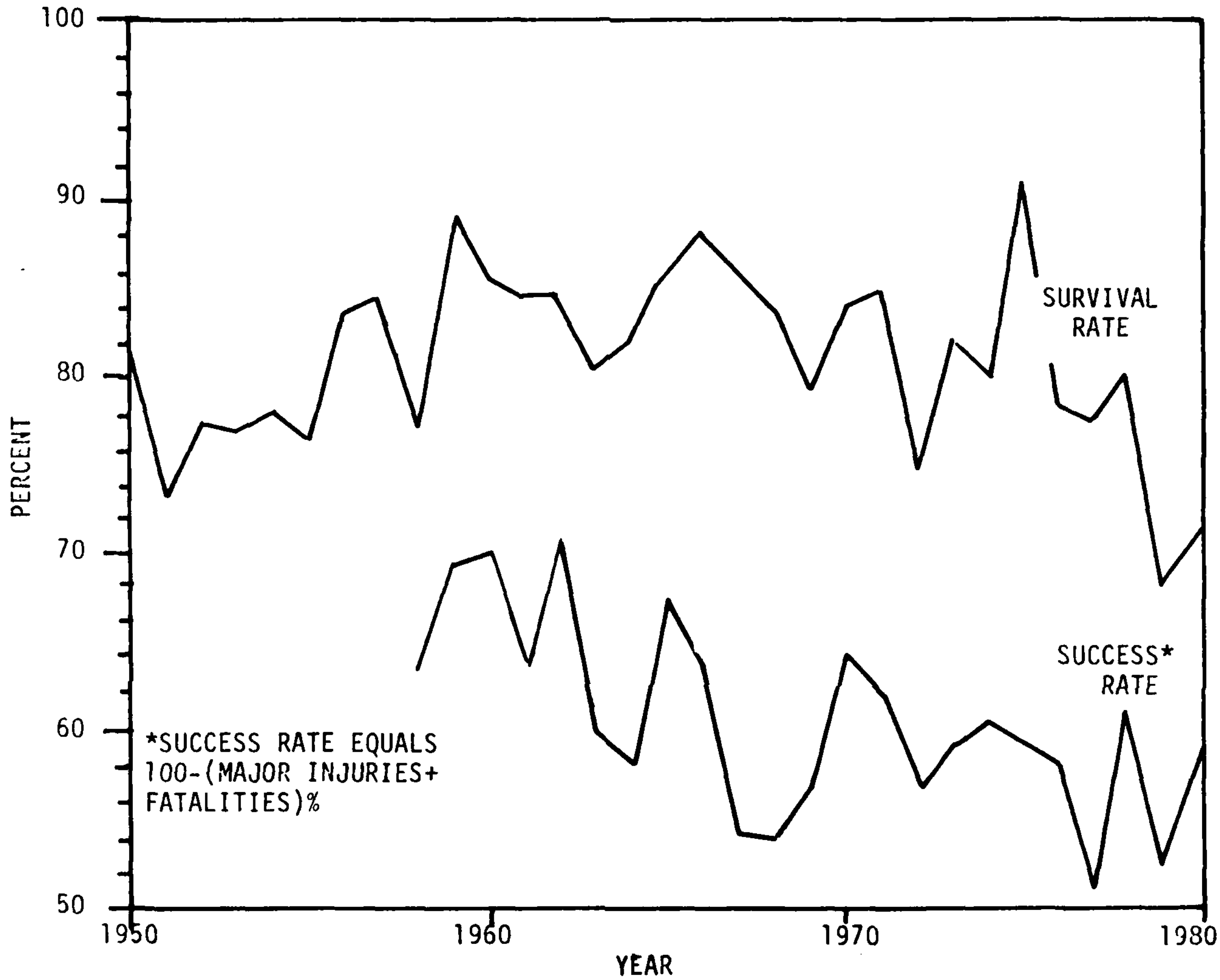


Figure 2. USAF Escape System Operational Experience

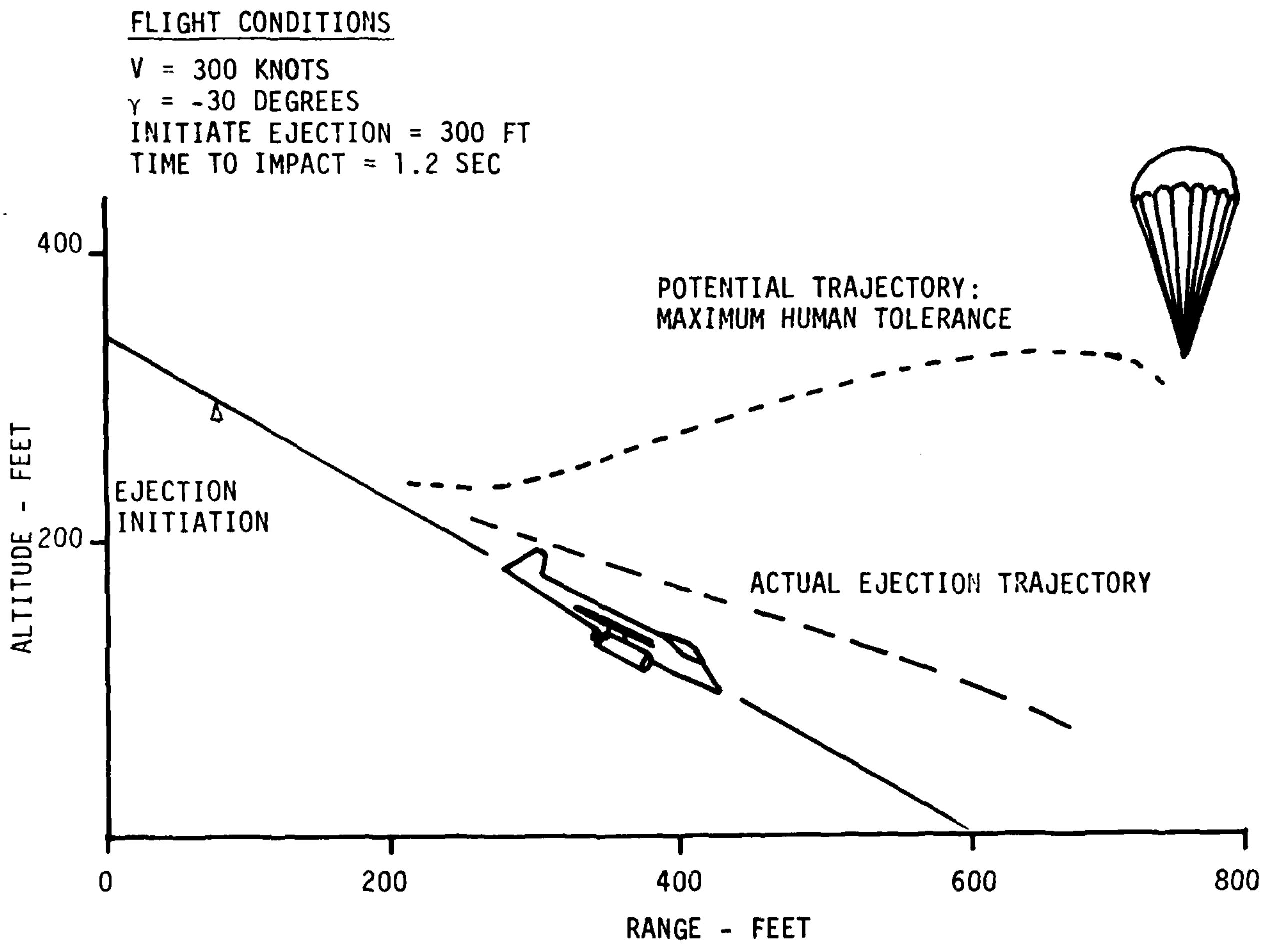


Figure 3. Close Air Support Aircraft Ejection Seat Trajectories

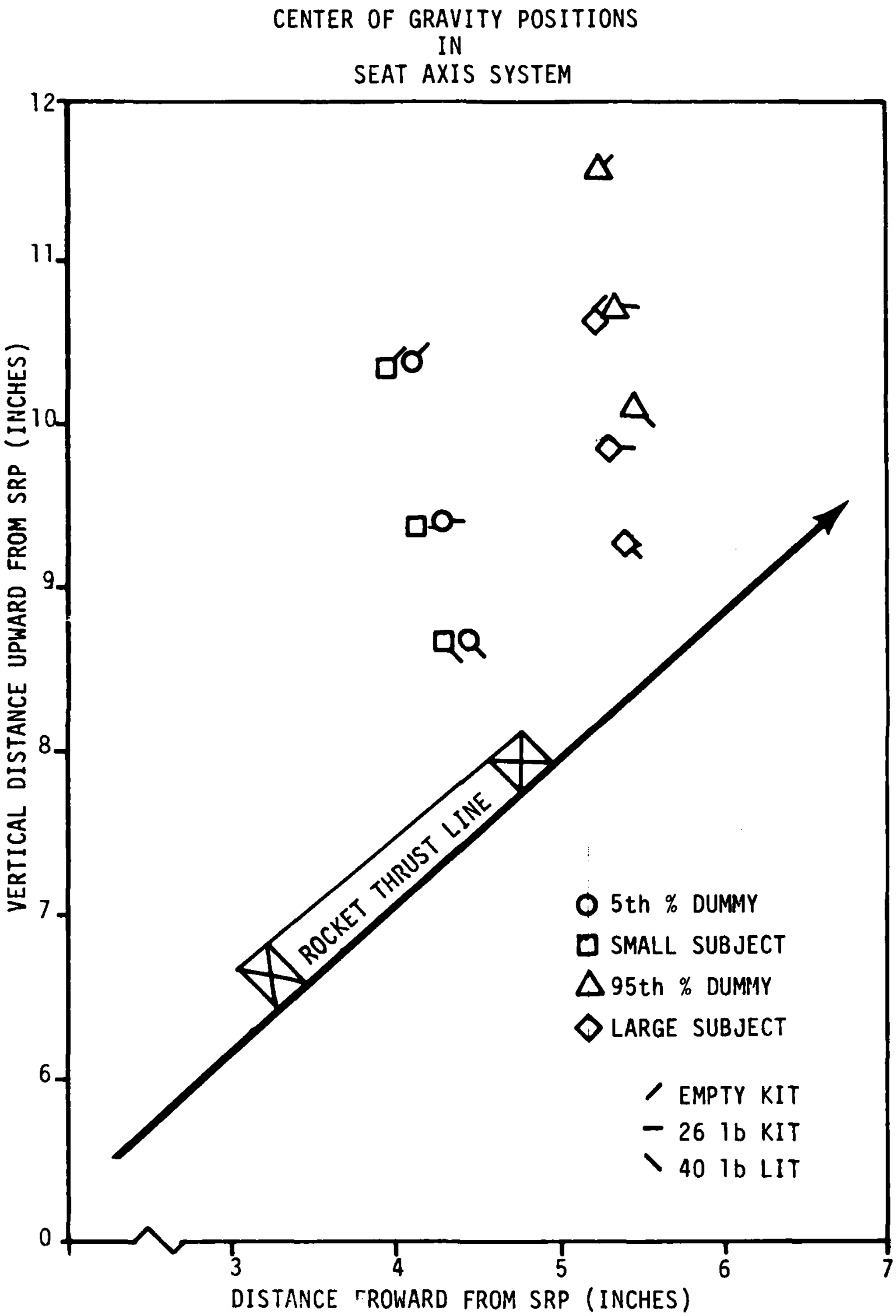


Figure 4. Center of Gravity Positions

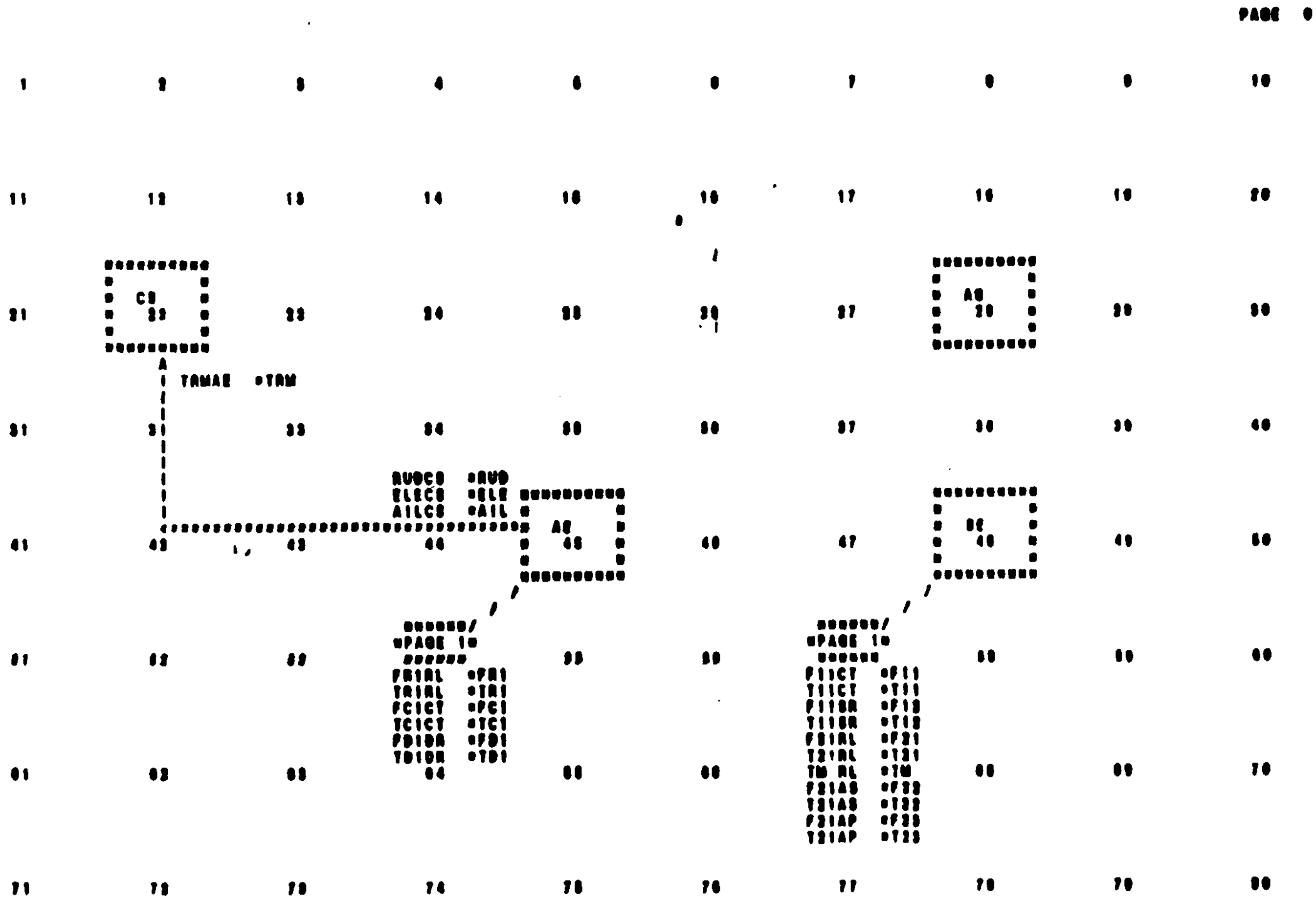


Figure 5. EASIEST MODEL 1 (TVC, AERO Surfaces, DART)

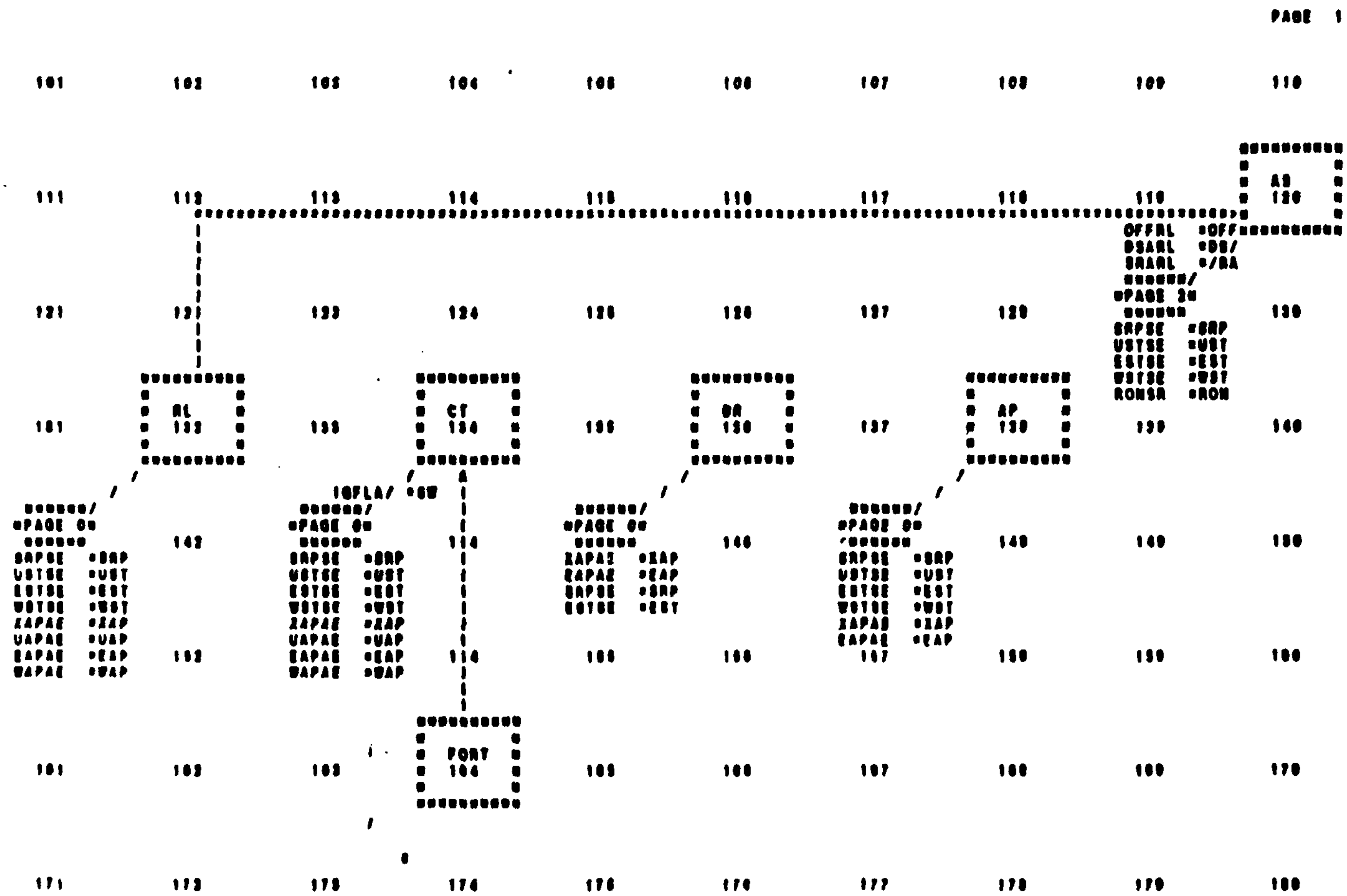


Figure 5 (Cont'd)

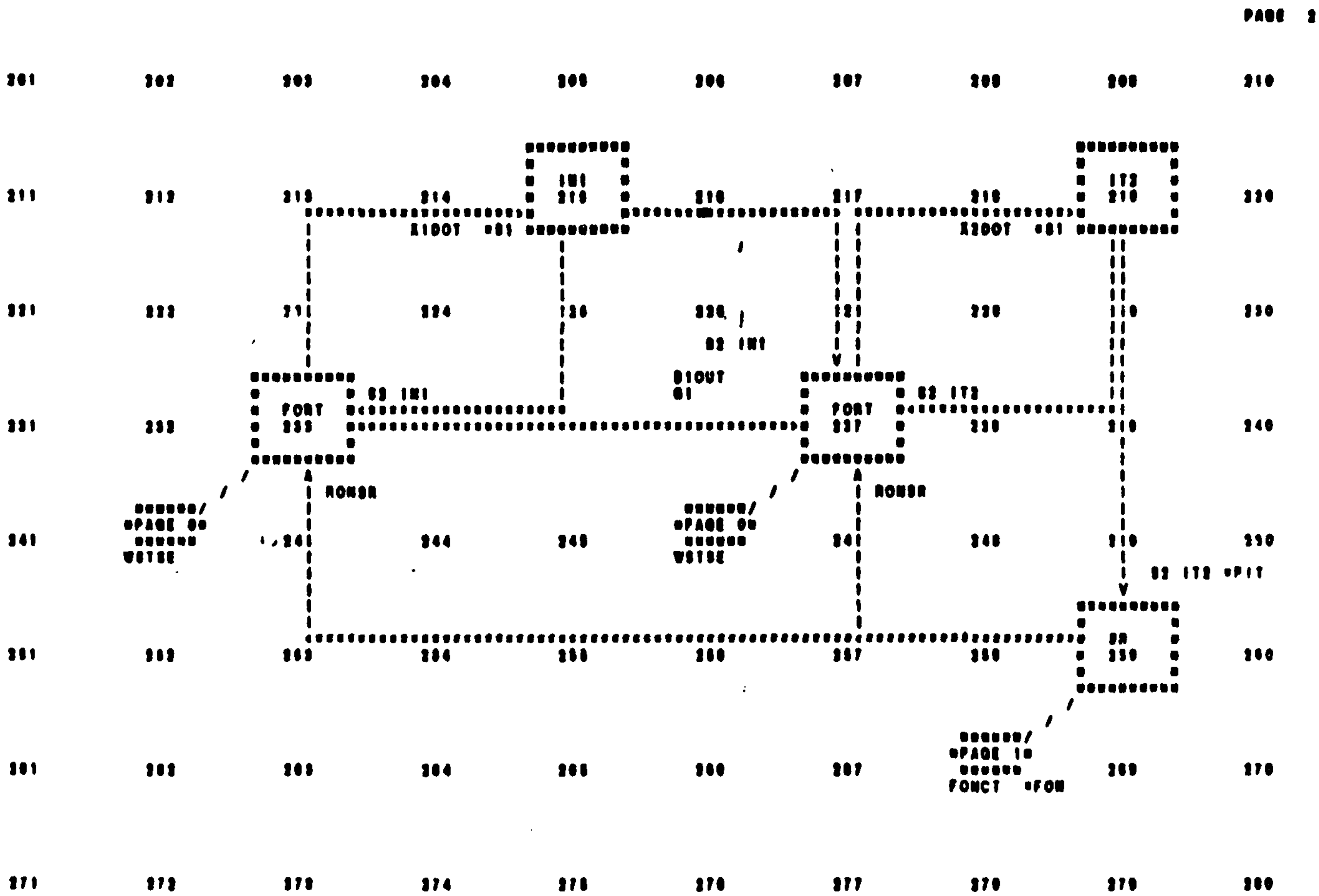


Figure 5 (Concluded)

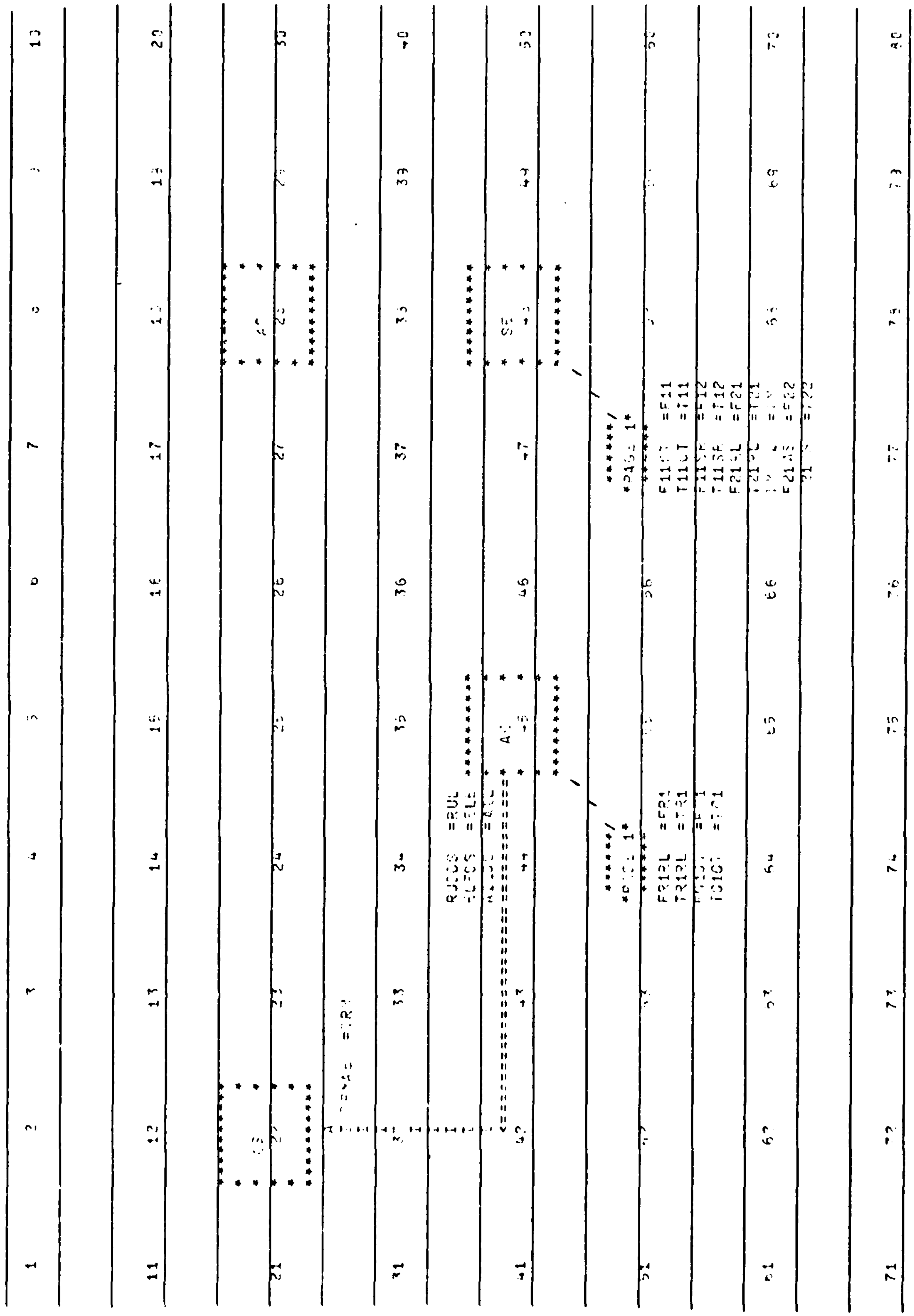


Figure 6. EASIEST MODEL 2 (TVC)

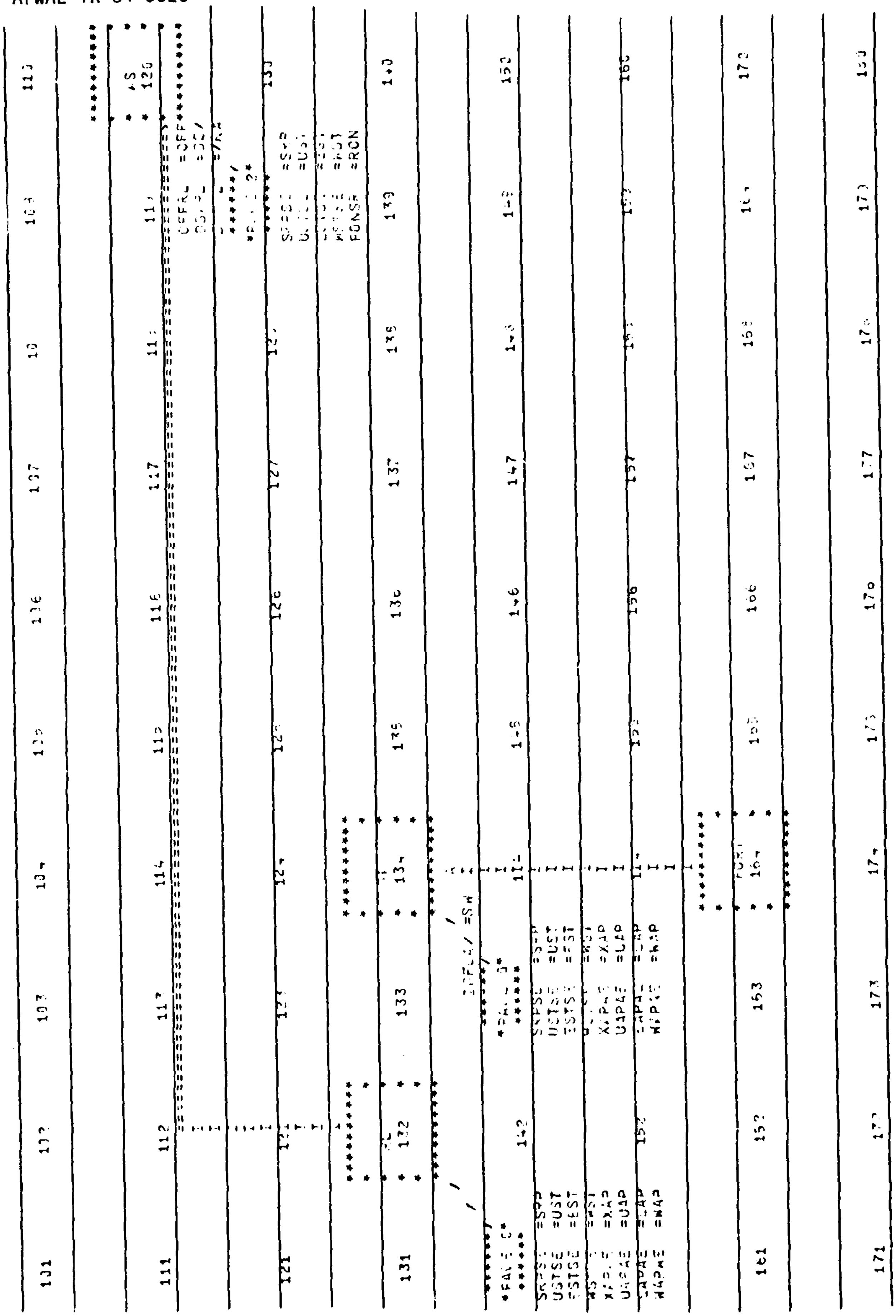


Figure 6 (Cont'd)

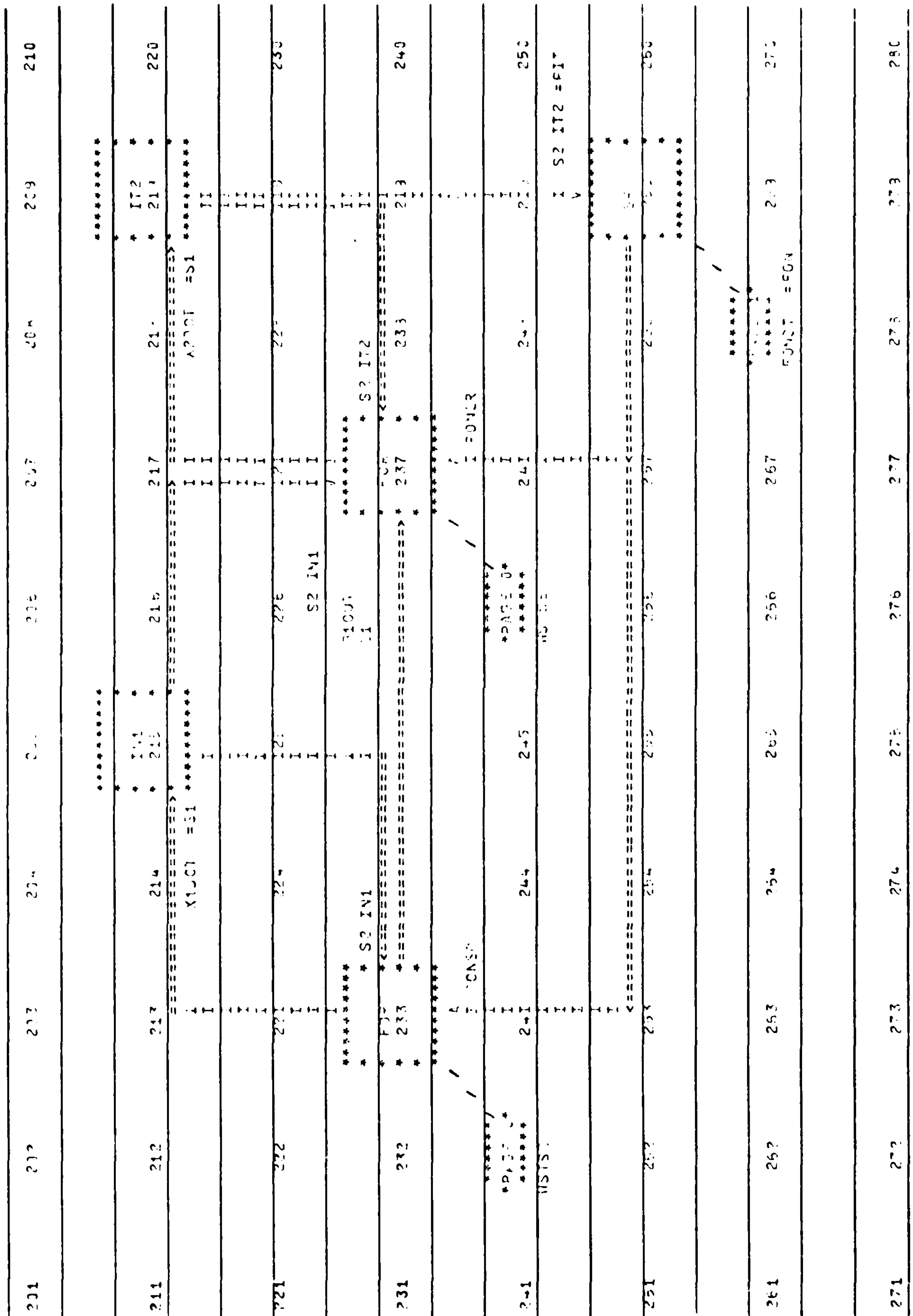


Figure 6 (Concluded)

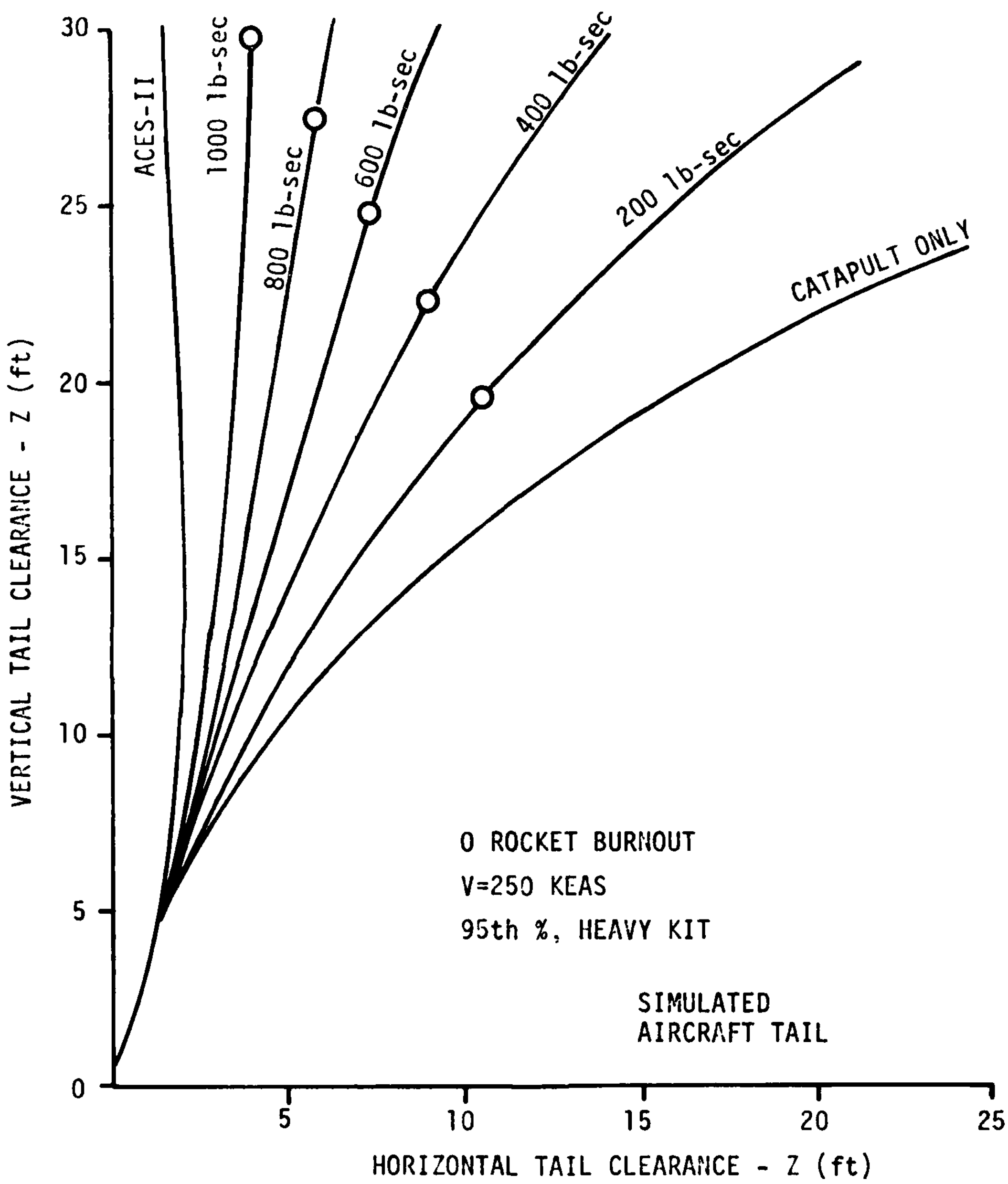


Figure 7. Tail Clearance - 250 KEAS

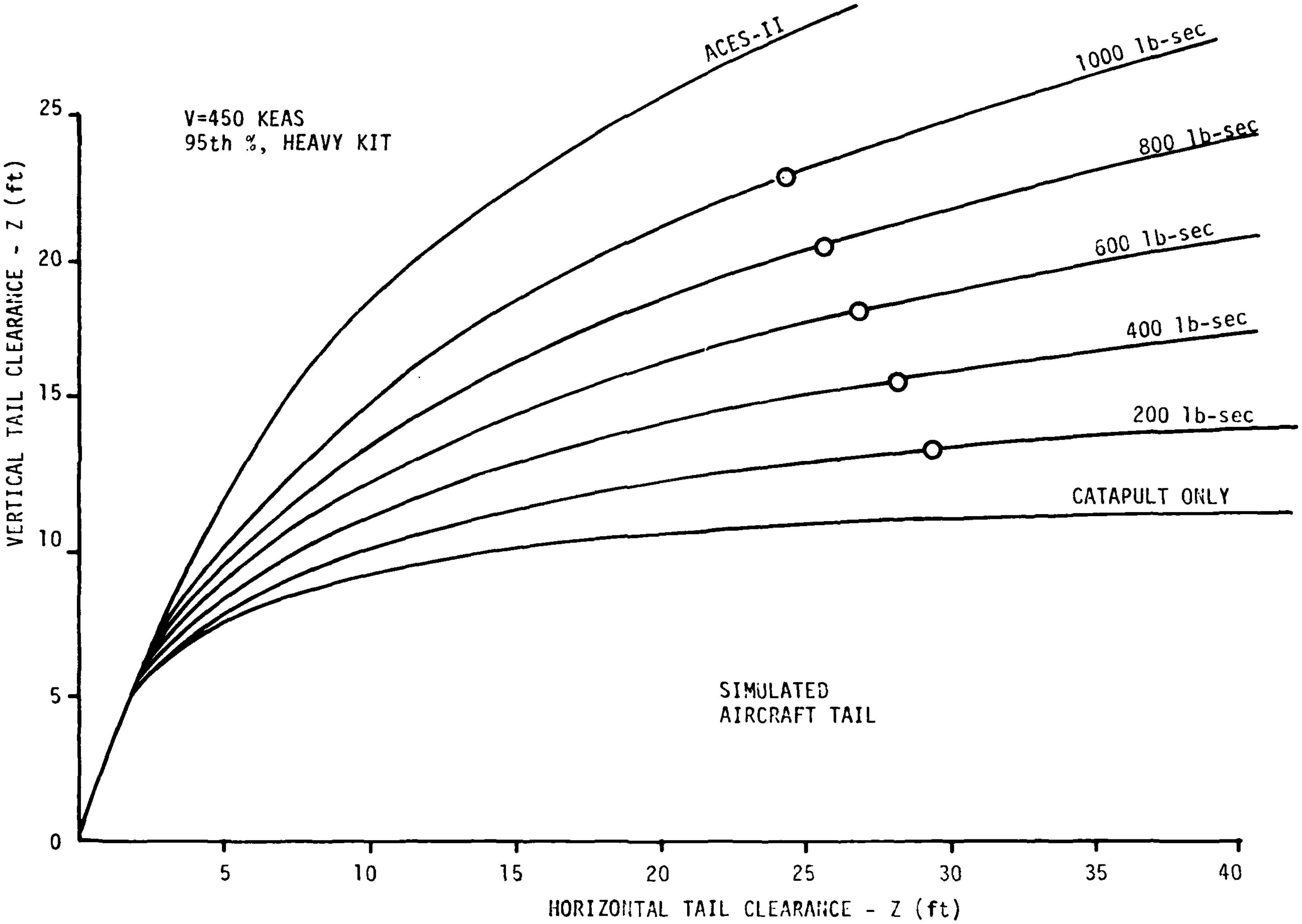


Figure 8. Tail Clearance - 450 KEAS

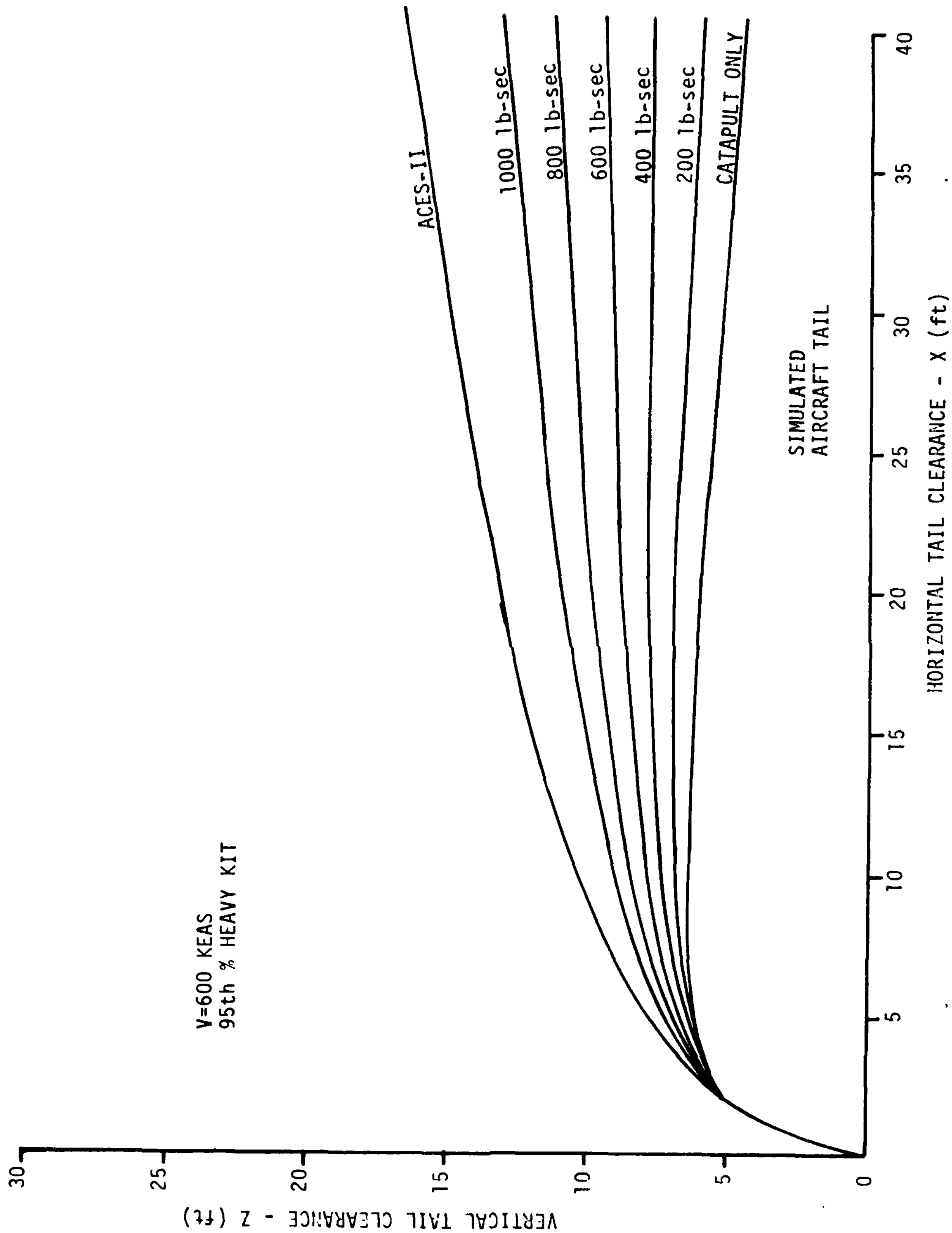


Figure 9. Tail Clearance - 600 KEAS

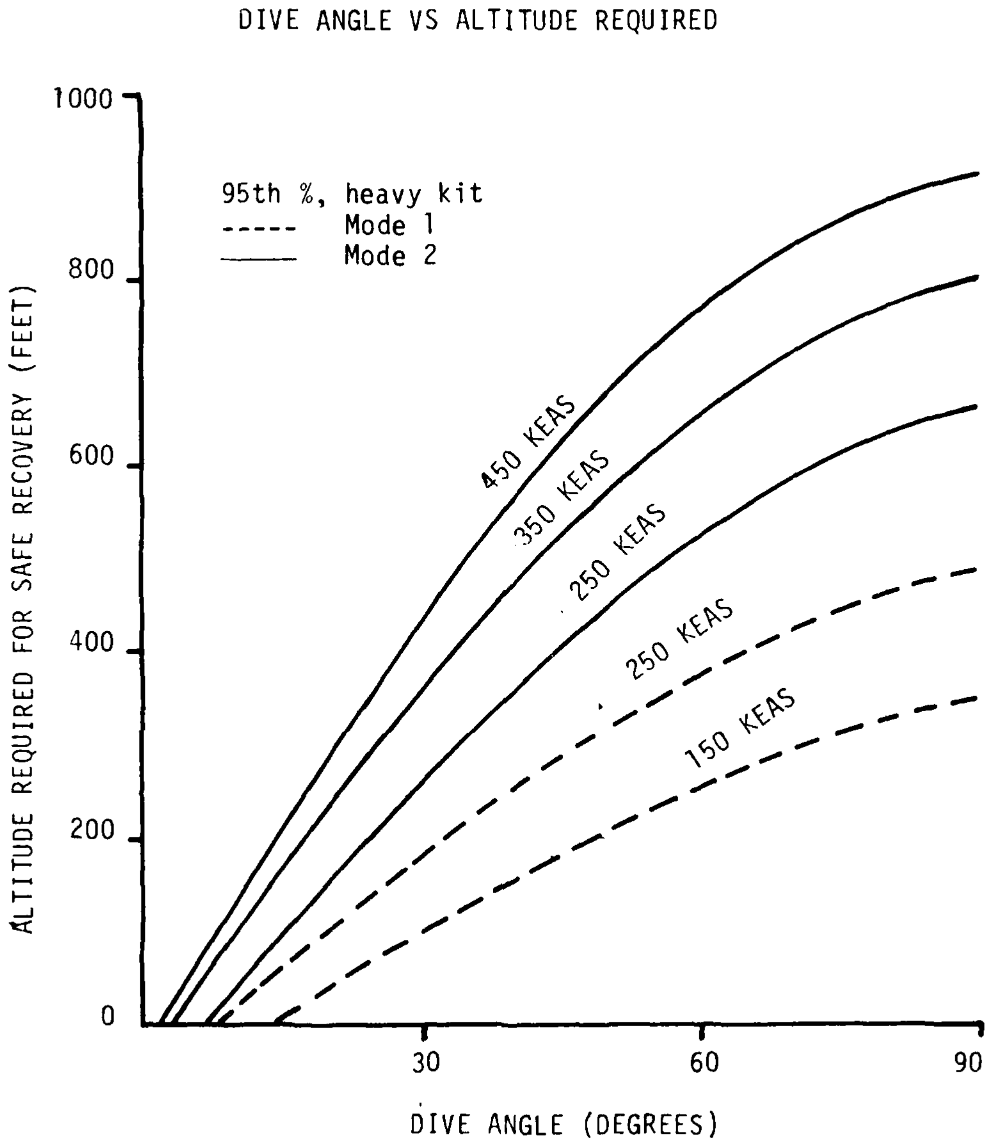


Figure 10. Dive Angle vs Altitude Required

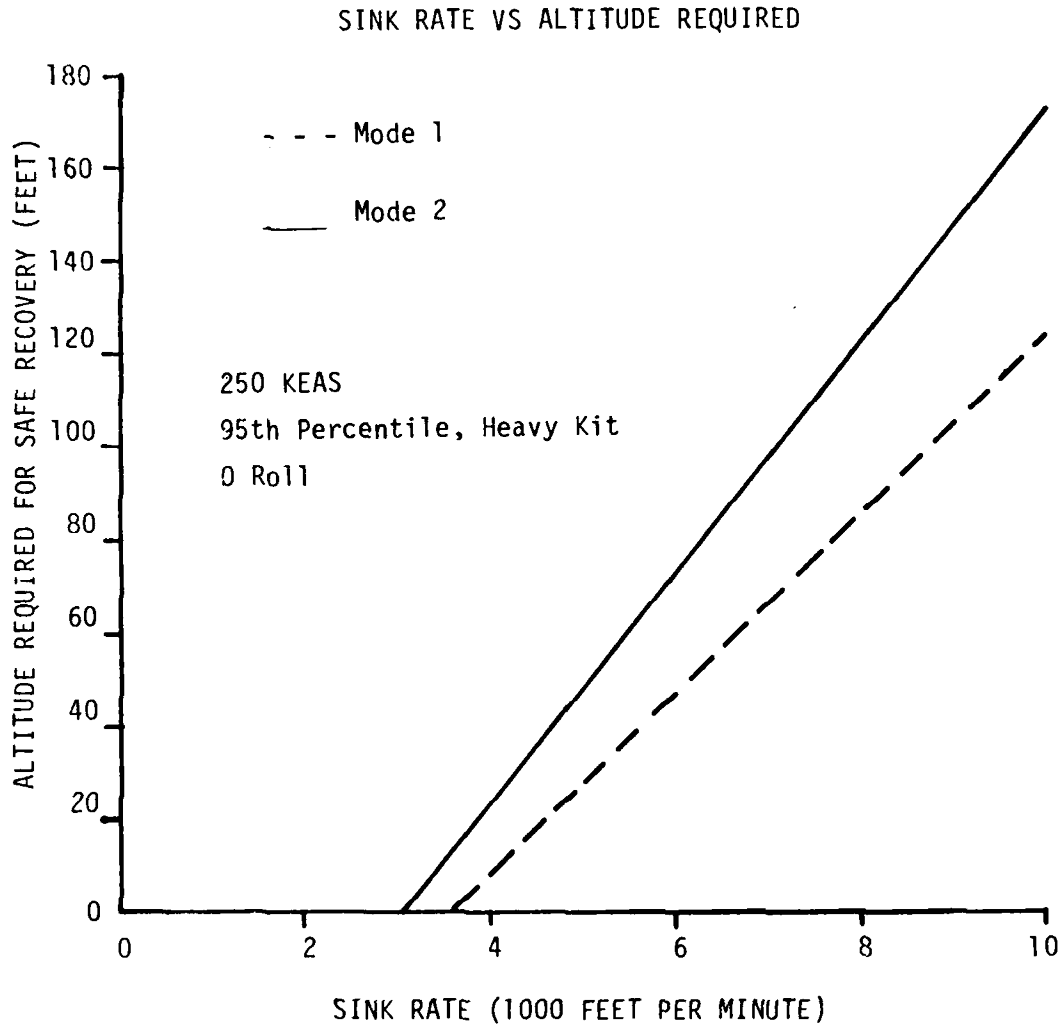
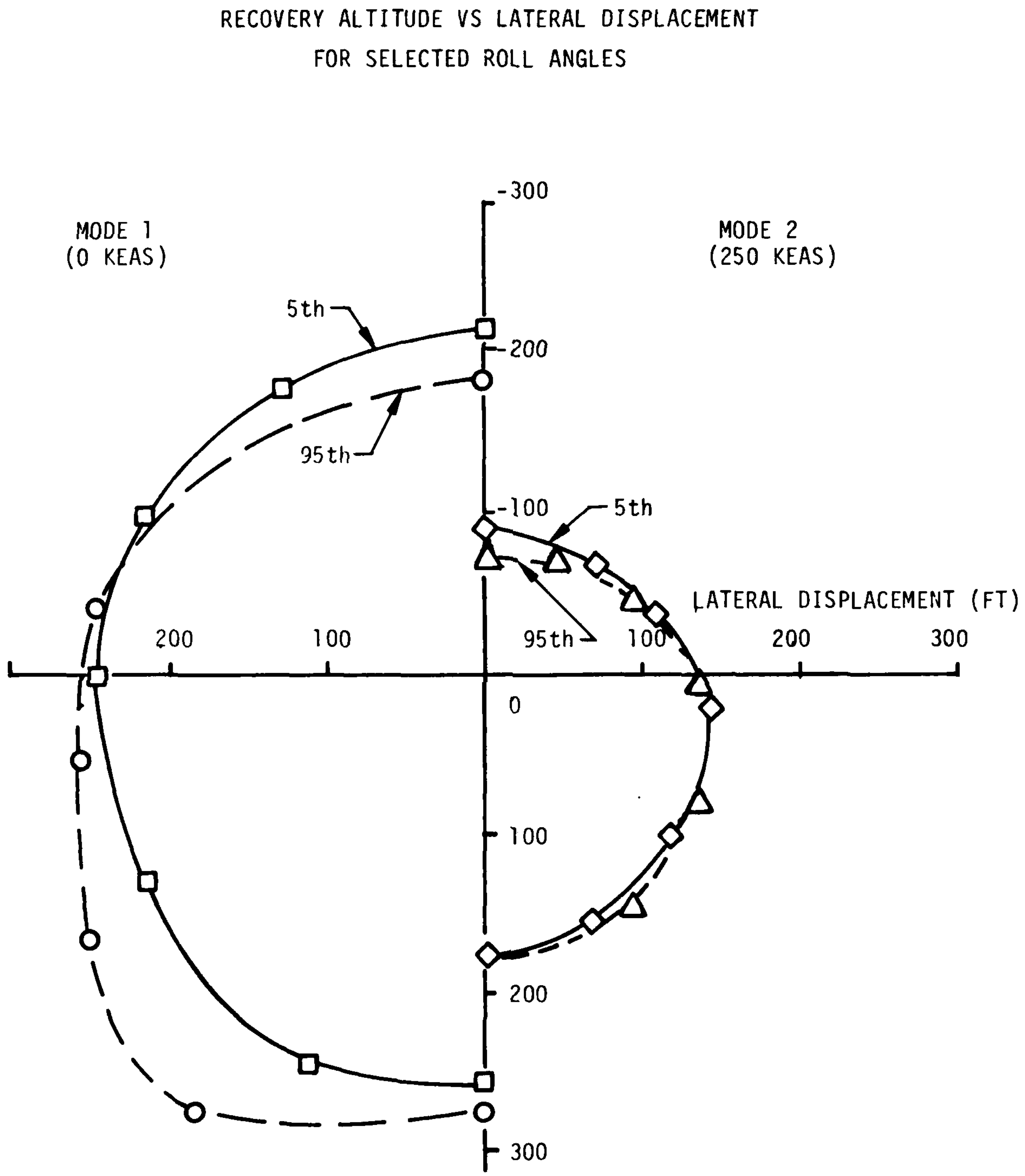


Figure 11. Sink Rate vs Altitude Required



NOTE: CONSECUTIVE ROLL ANGLES PLOTTED OF 0, 30, 60, 90, 120, 150 & 180 DEGREES

Figure 12. Roll Angle vs Altitude Required

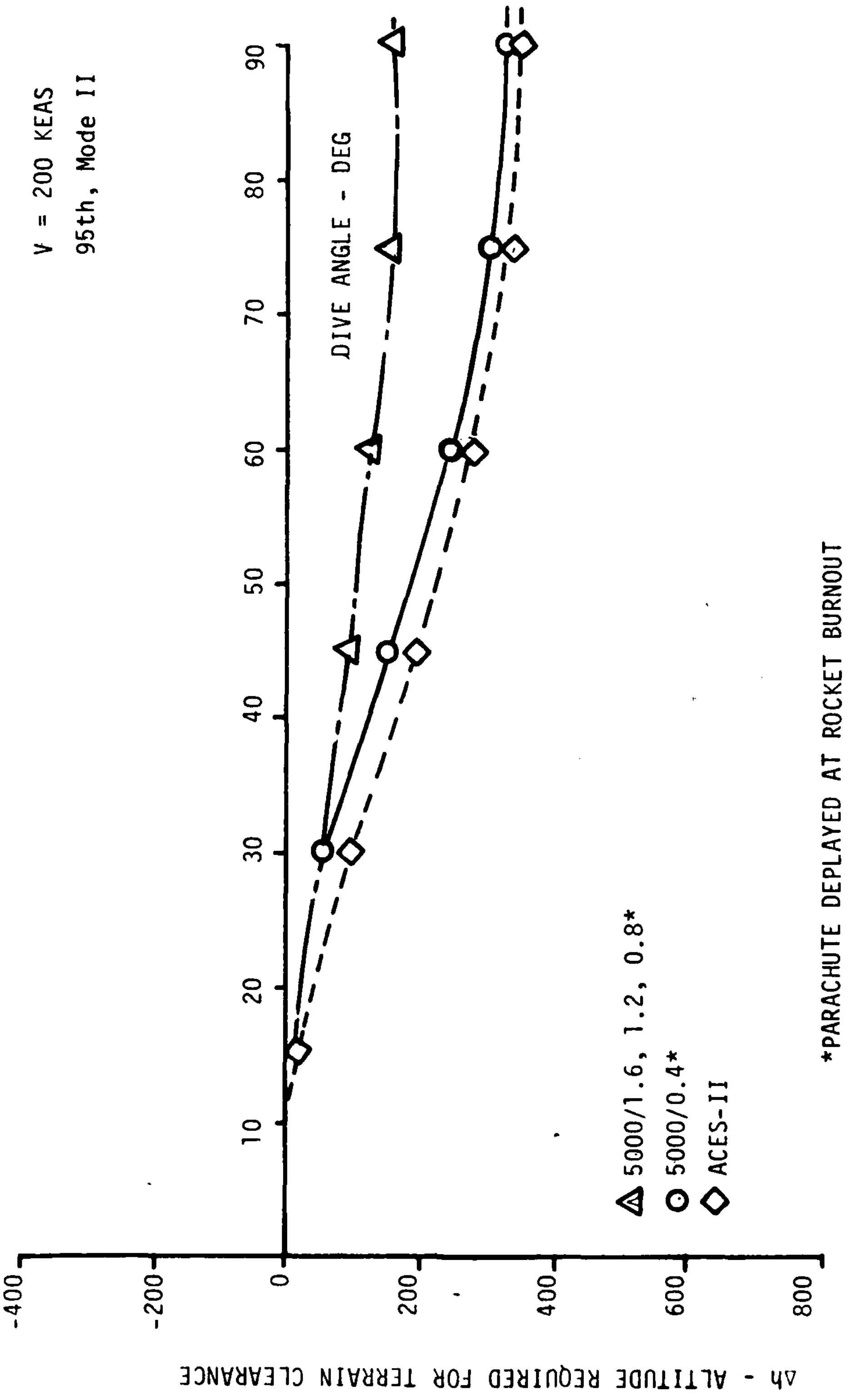


Figure 13. Terrain Clearance - 200 KEAS

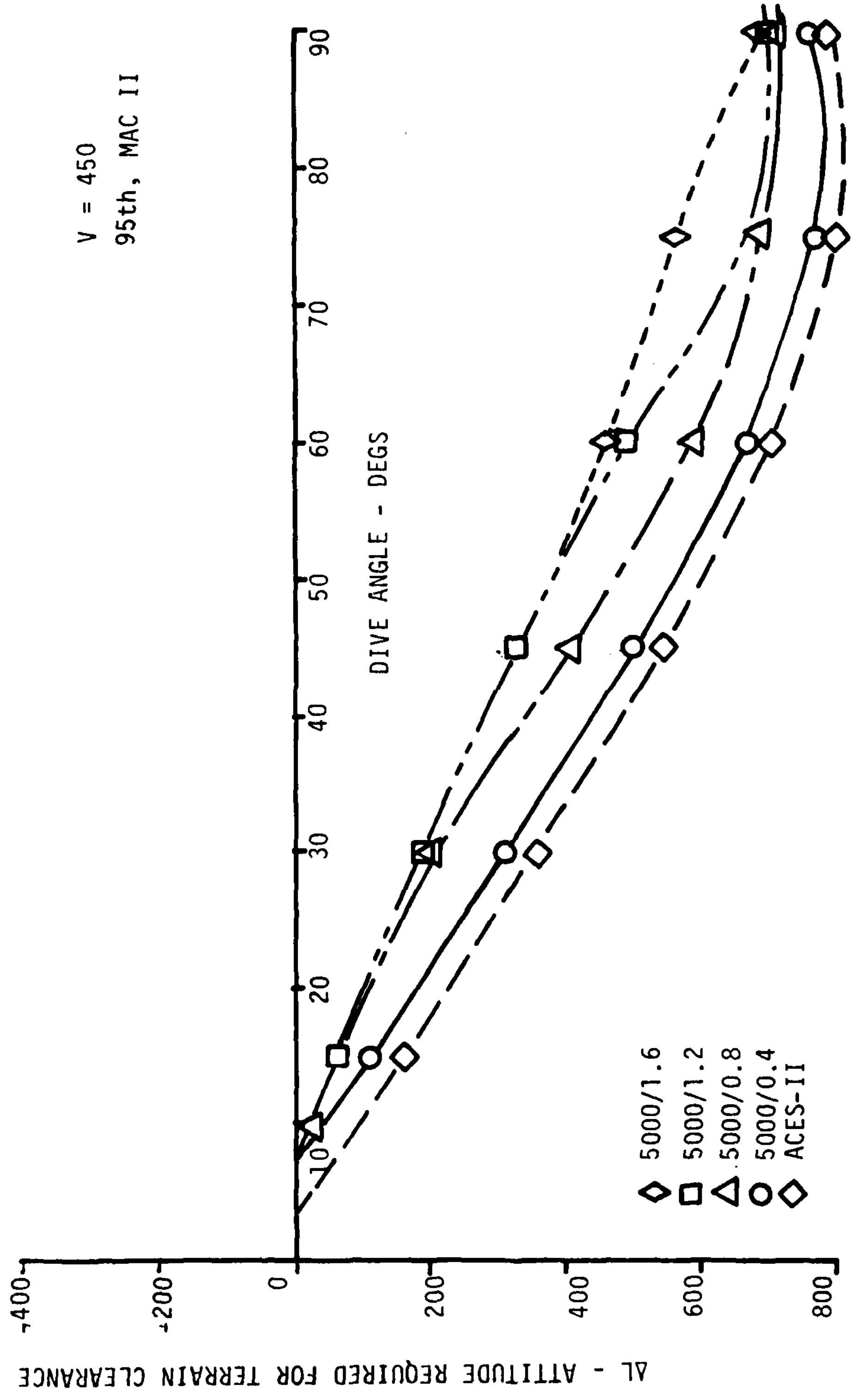


Figure 14. Terrain Clearance - 450 KEAS

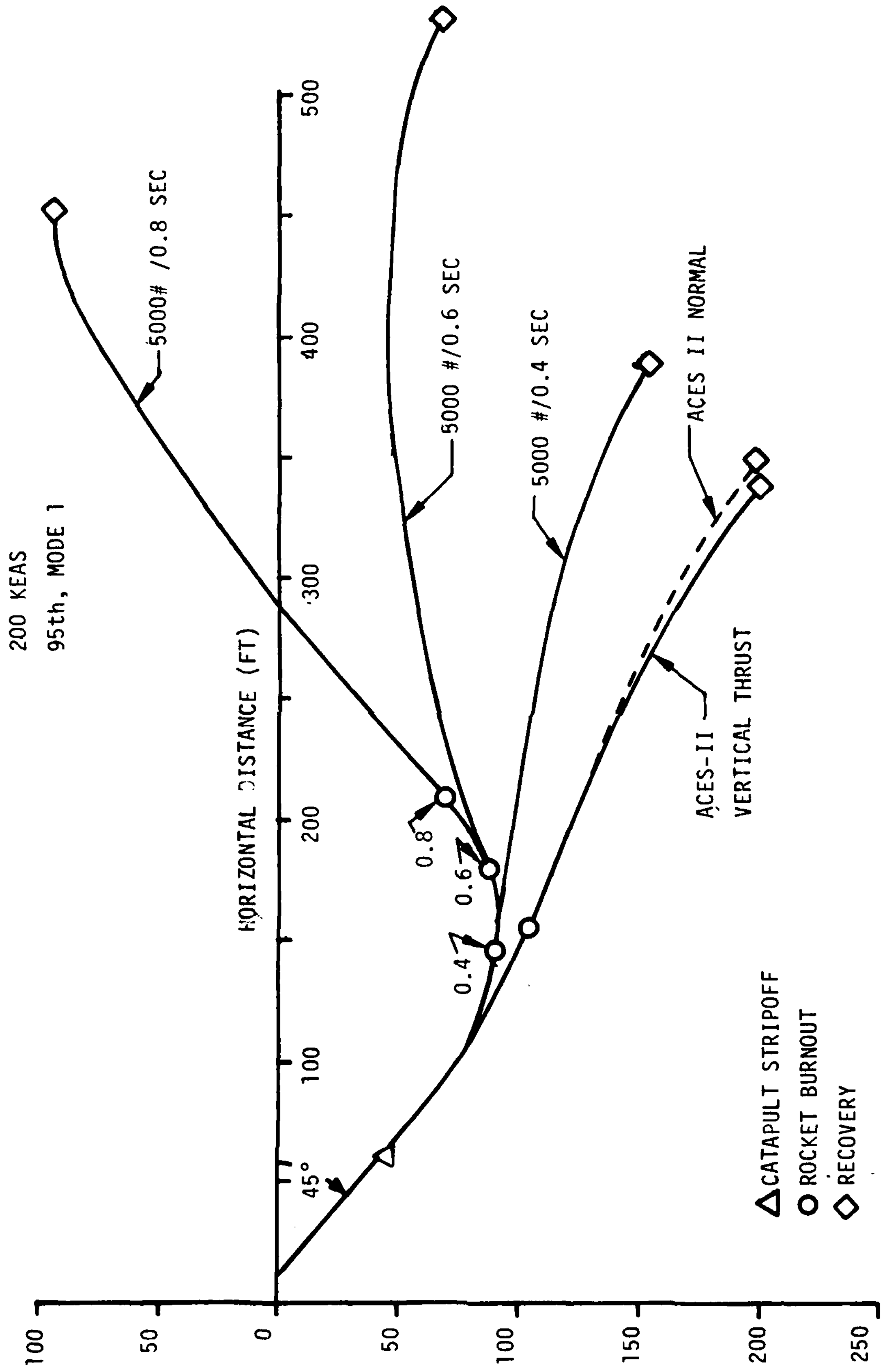


Figure 15. Rocket Thrust Duration Comparison

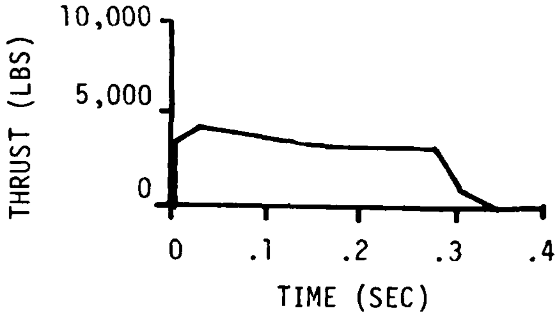


Figure 16. Baseline Case Thrust vs Time Curve

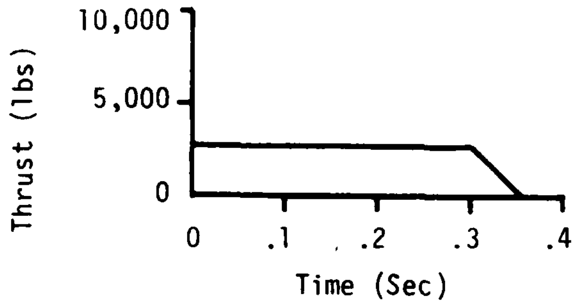


Figure 17. Case 1 Thrust vs Time Curve

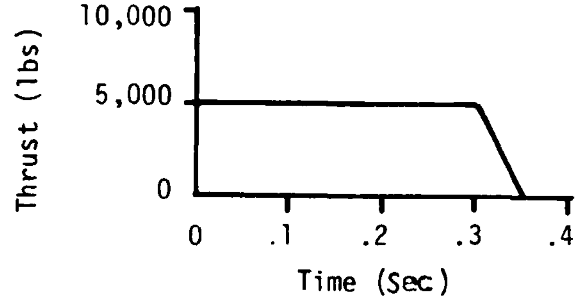


Figure 18. Case 2 Thrust vs Time Curve

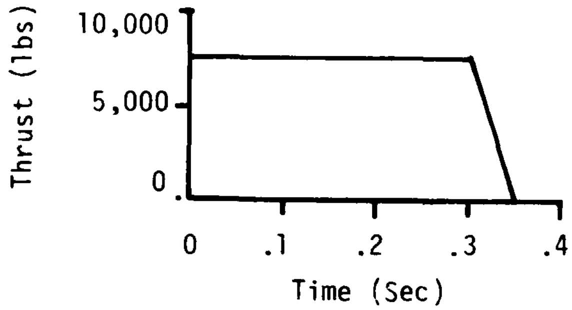


Figure 19. Case 3 Thrust vs Time Curve

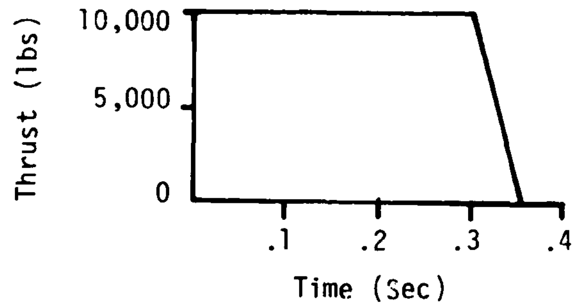


Figure 20. Case 4 Thrust vs Time Curve

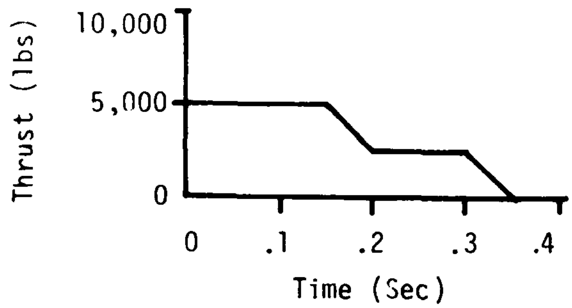


Figure 21. Case 5 Thrust vs Time Curve

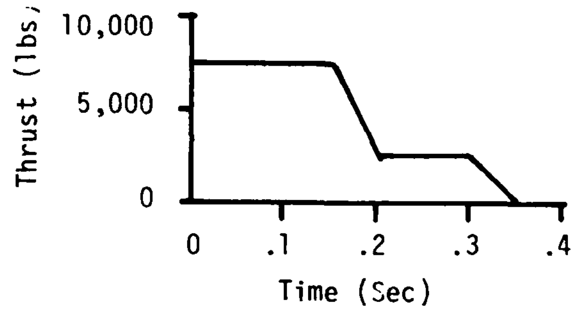


Figure 22. Case 6 Thrust vs Time Curve

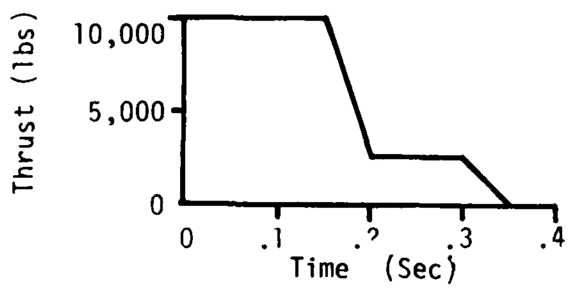


Figure 23. Case 7 Thrust vs Time Curve

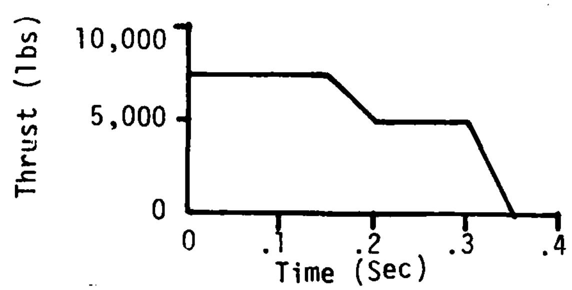


Figure 24. Case 8 Thrust vs Time Curve

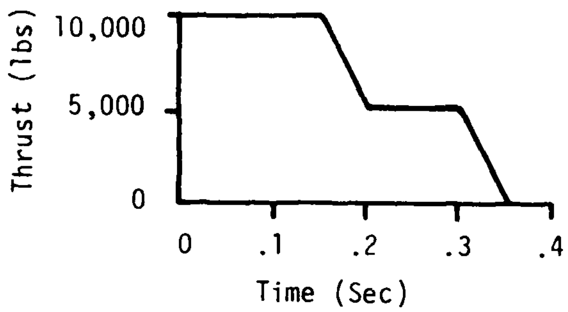


Figure 25. Case 9 Thrust vs Time Curve

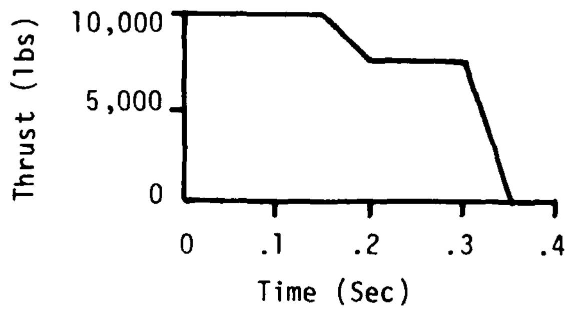


Figure 26. Case 10 Thrust vs Time Curve

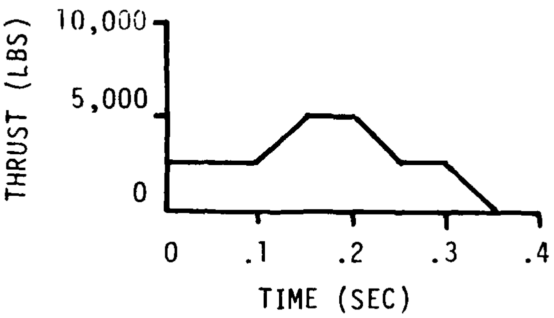


Figure 27. Case 11 Thrust vs Time Curve

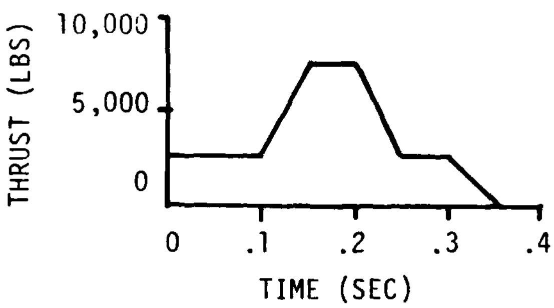


Figure 28. Case 12 Thrust vs Time Curve

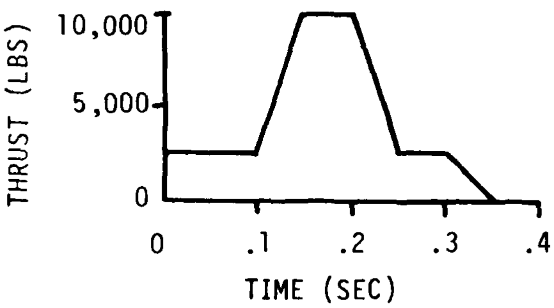


Figure 29. Case 13 Thrust vs Time Curve

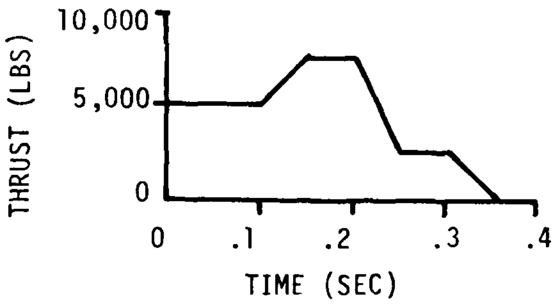


Figure 30. Case 14 Thrust vs Time Curve

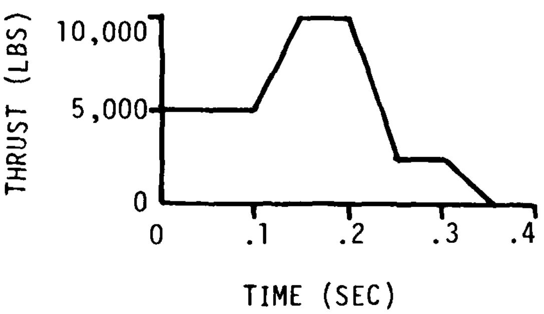


Figure 31. Case 15 Thrust vs Time Curve

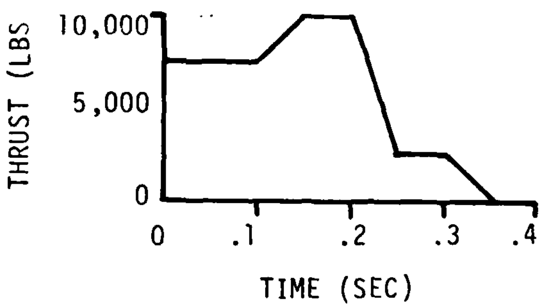


Figure 32. Case 16 Thrust vs Time Curve

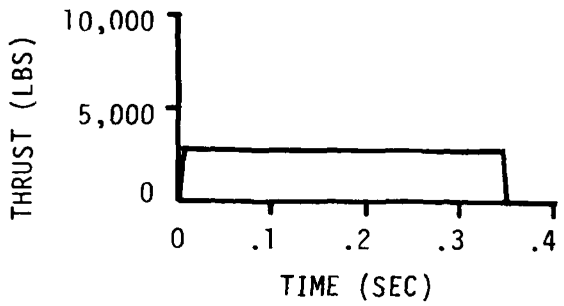


Figure 33. Case 17 Thrust vs Time Curve

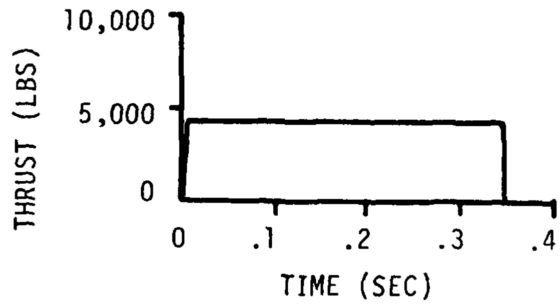


Figure 34. Case 18 Thrust vs Time Curve

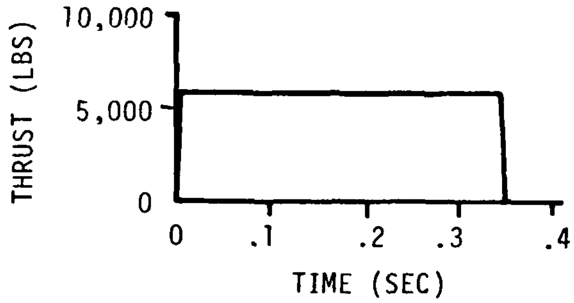


Figure 35. Case 19 Thrust vs Time Curve

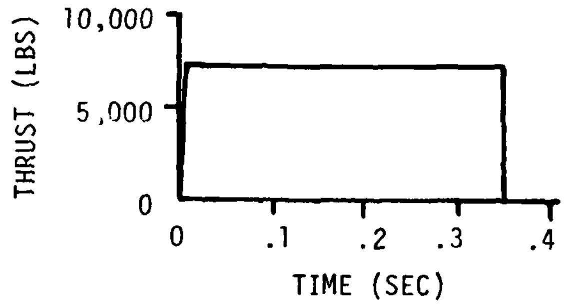


Figure 36. Case 20 Thrust vs Time Curve

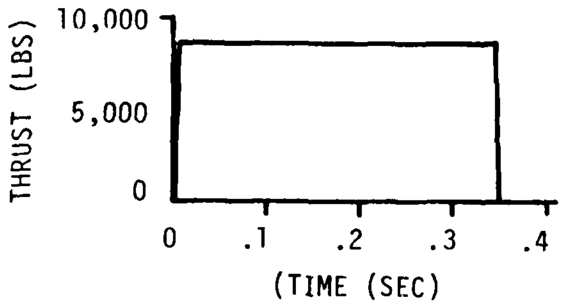


Figure 37. Case 21 Thrust vs Time Curve

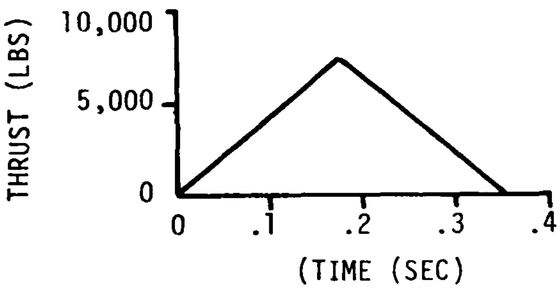


Figure 38. Case 22 Thrust vs Time Curve

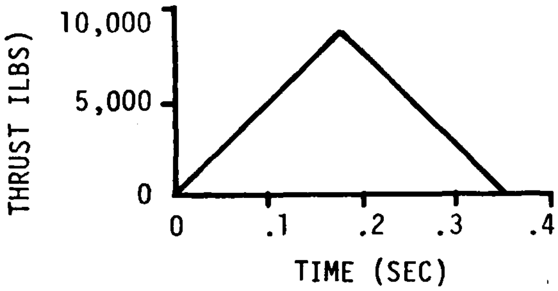


Figure 39. Case 23 Thrust vs Time Curve

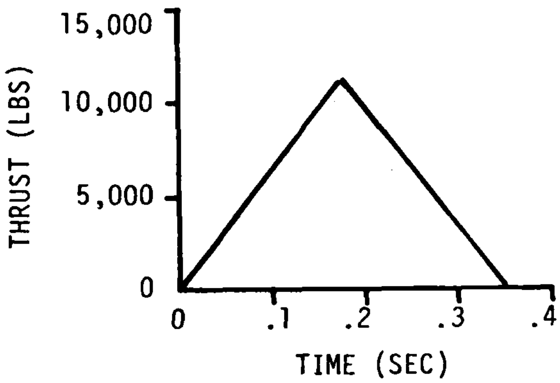


Figure 40. Case 24 Thrust vs Time Curve

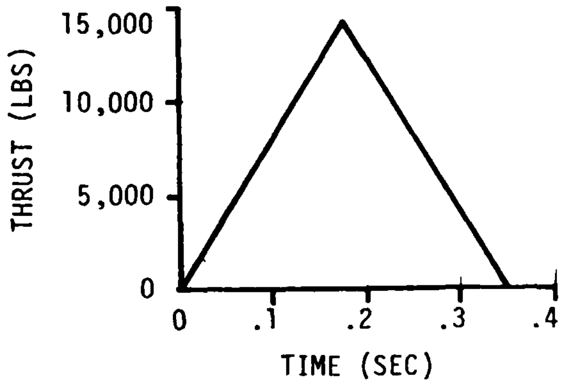


Figure 41. Case 25 Thrust vs Time Curve

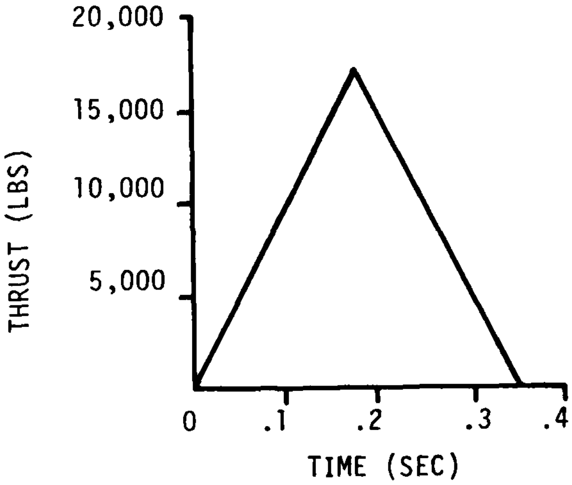


Figure 42. Case 26 Thrust vs Time Curve

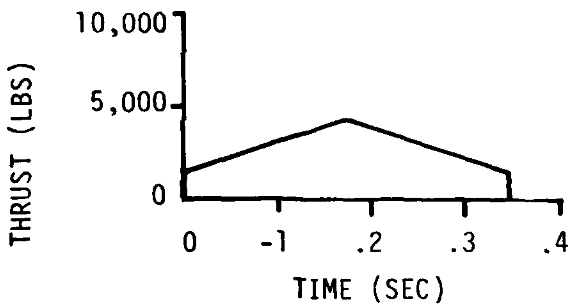


Figure 43. Case 27 Thrust vs Time Curve

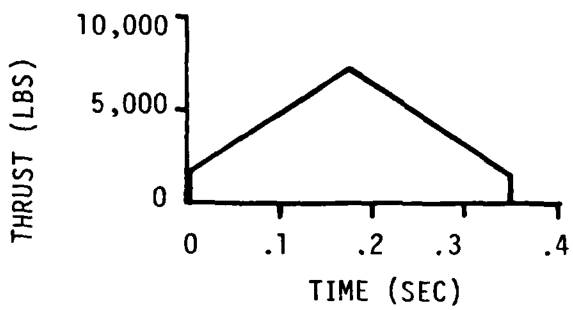


Figure 44. Case 28 Thrust vs Time Curve

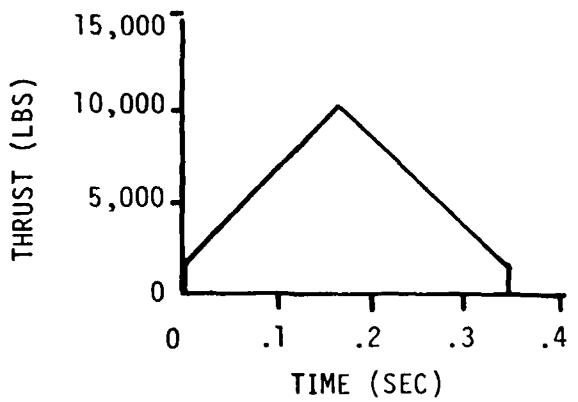


Figure 45. Case 29 Thrust vs Time Curve

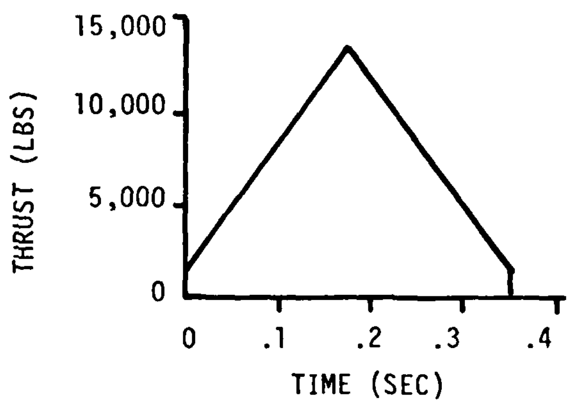


Figure 46. Case 30 Thrust vs Time Curve

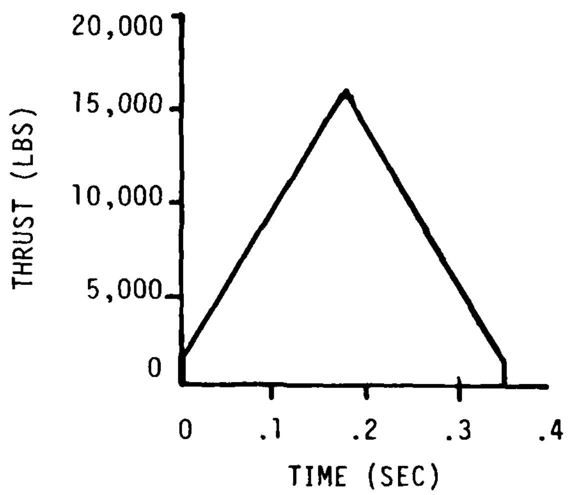


Figure 47. Case 31 Thrust vs Time Curve

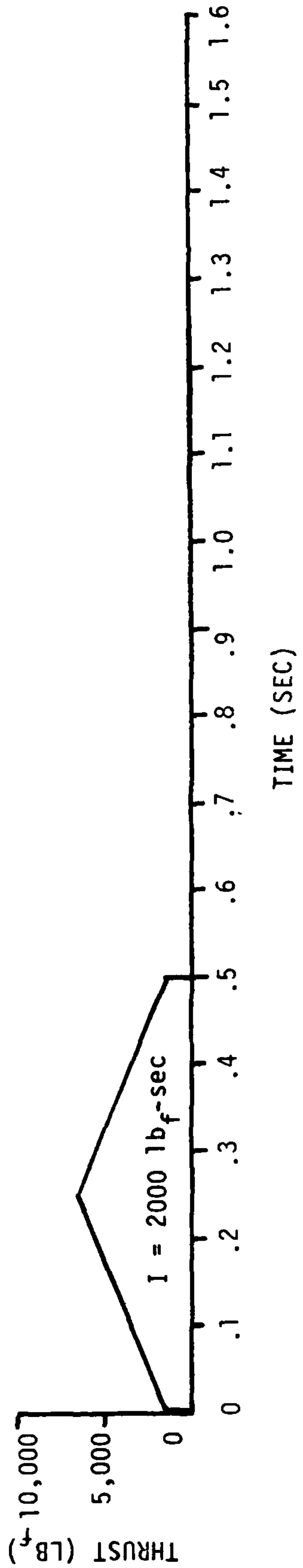


Figure 48. Case 32 Thrust vs Time Curve

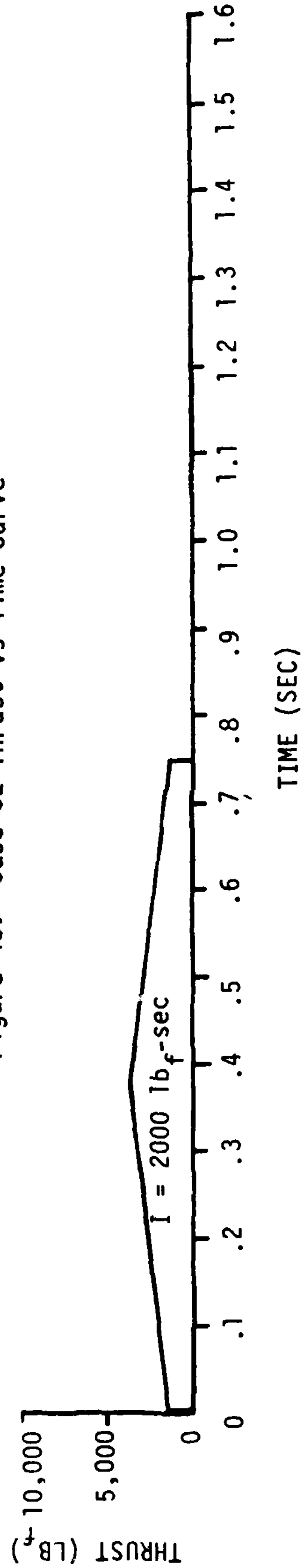


Figure 49. Case 33 Thrust vs Time Curve

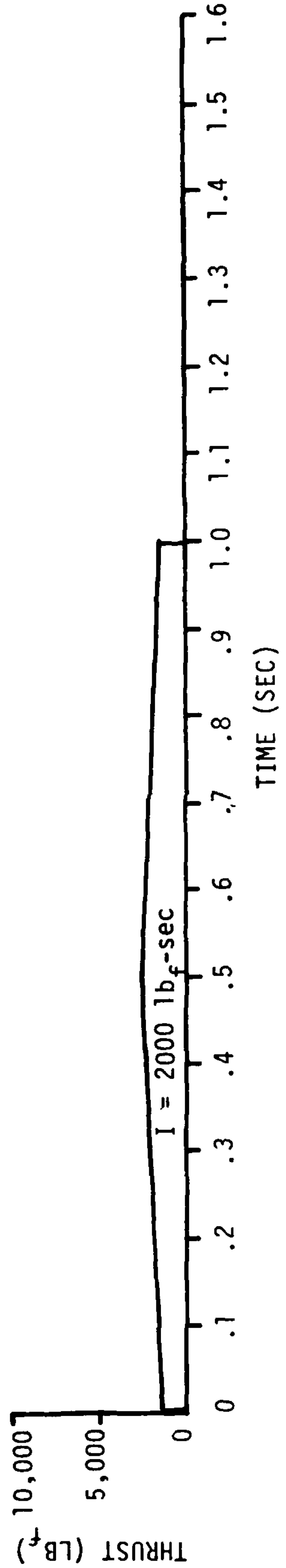


Figure 50. Case 34 Thrust vs Time Curve

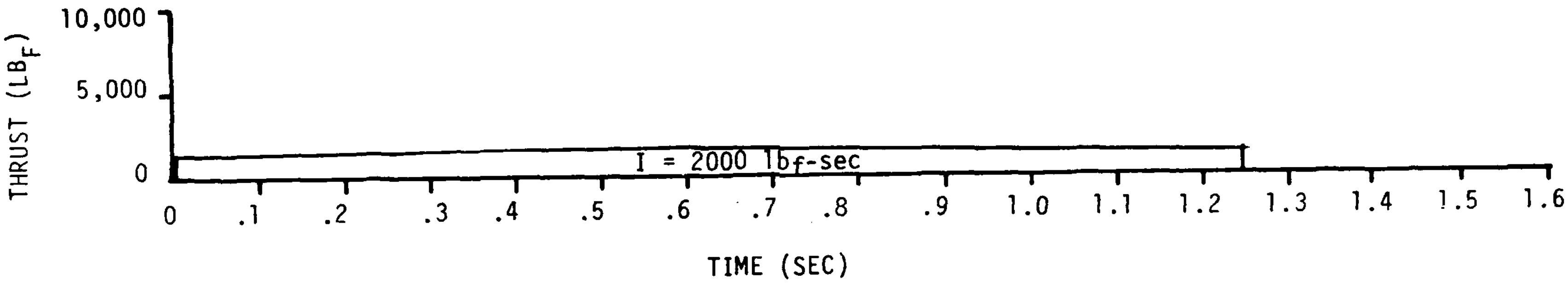


Figure 51. Case 35 Thrust vs Time Curve

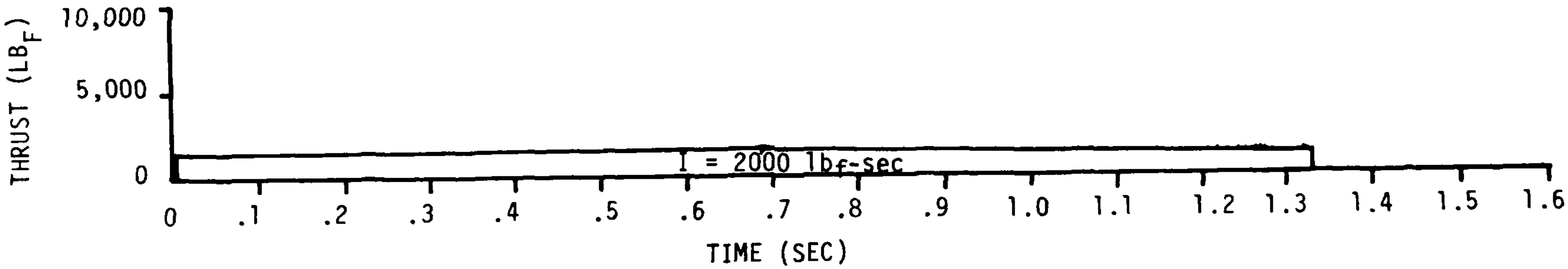


Figure 52. Case 36 Thrust vs Time Curve

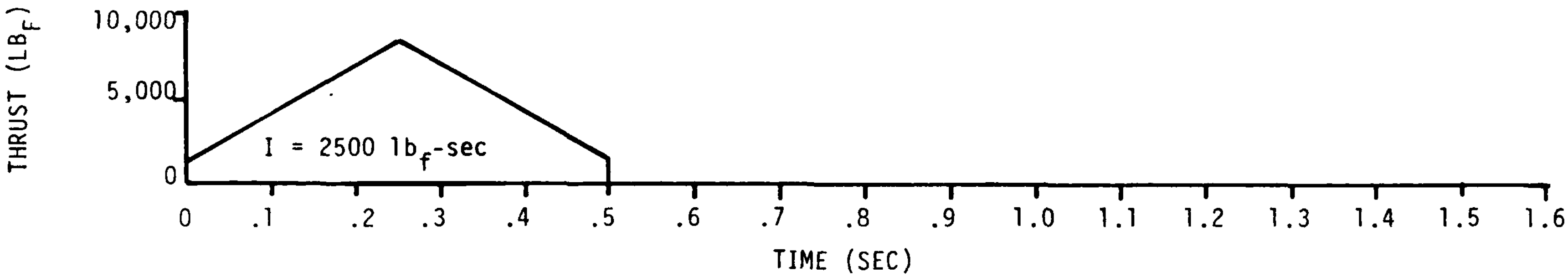


Figure 53. Case 37 Thrust vs Time Curve

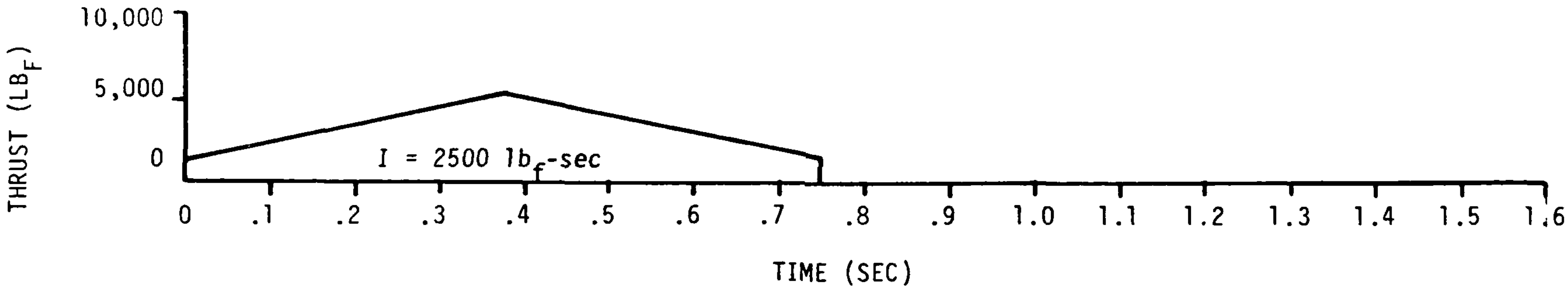


Figure 54. Case 38 Thrust vs Time Curve

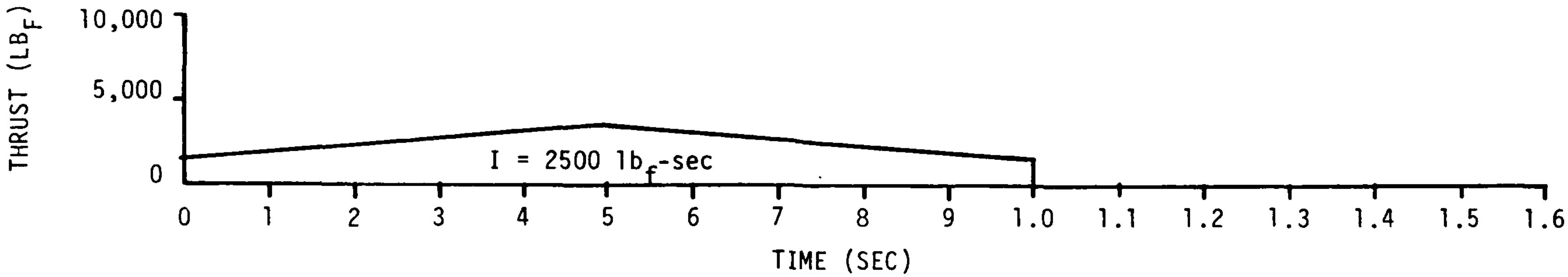


Figure 55. Case 39 Thrust vs Time Curve

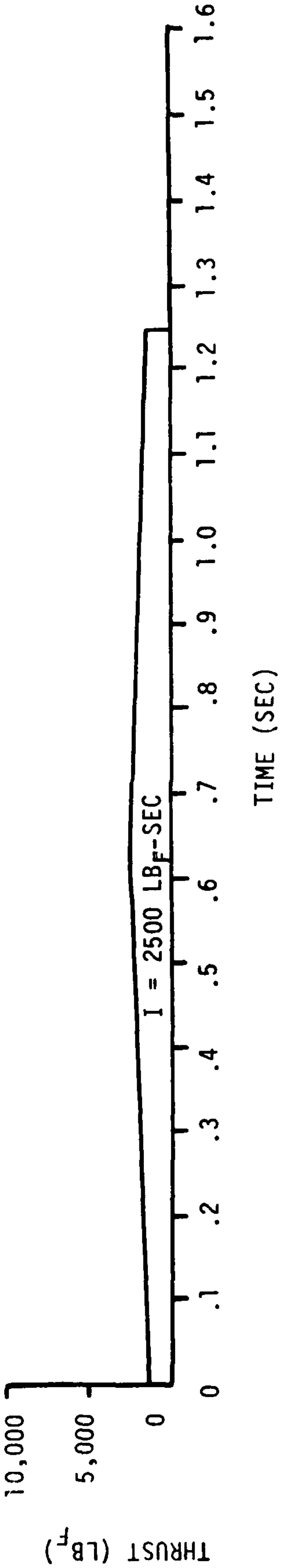


Figure 56. Case 40 Thrust vs Time Curve

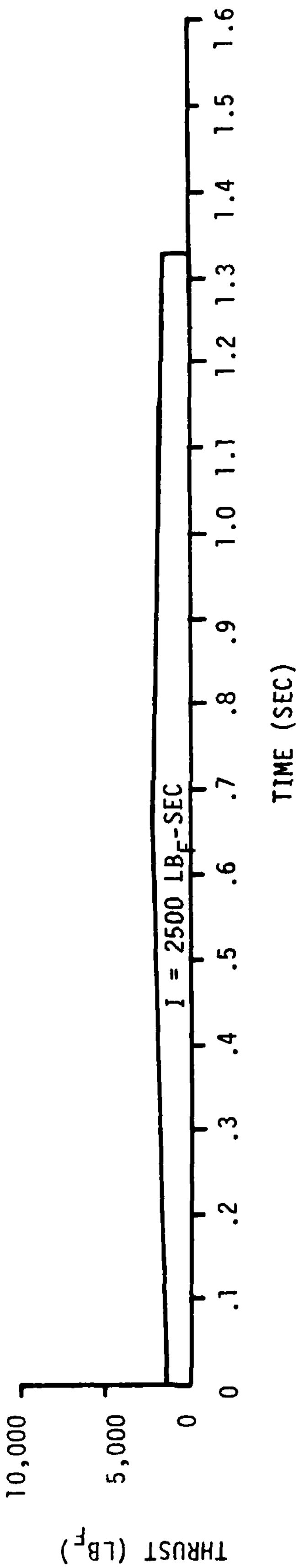


Figure 57. Case 41 Thrust vs Time Curve

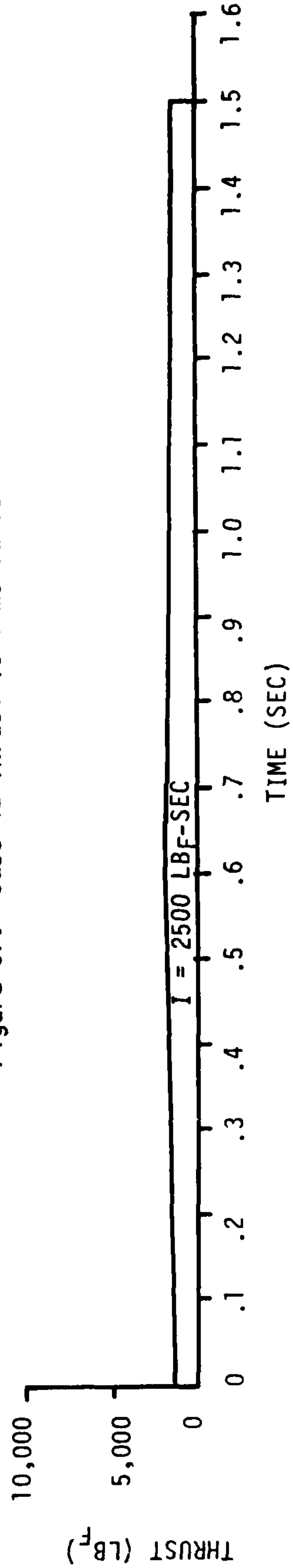


Figure 58. Case 42 Thrust vs Time Curve

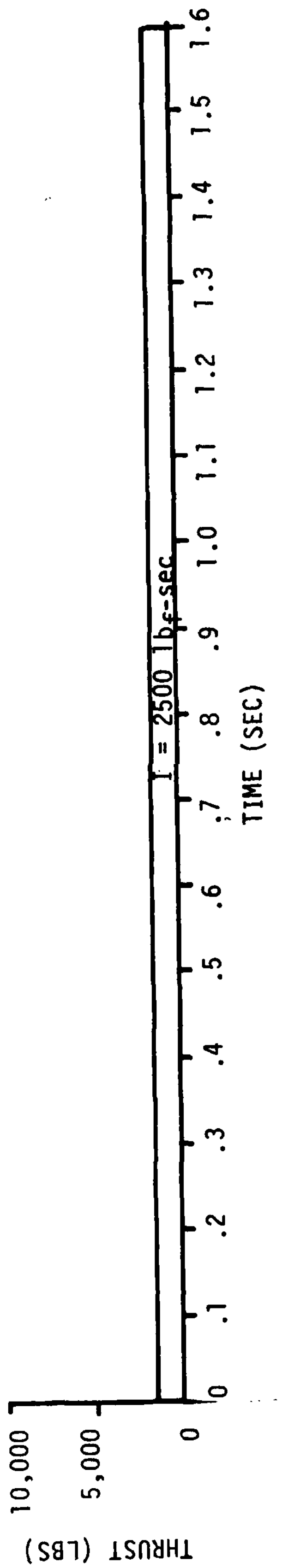


Figure 59. Case 43 Thrust vs Time Curve

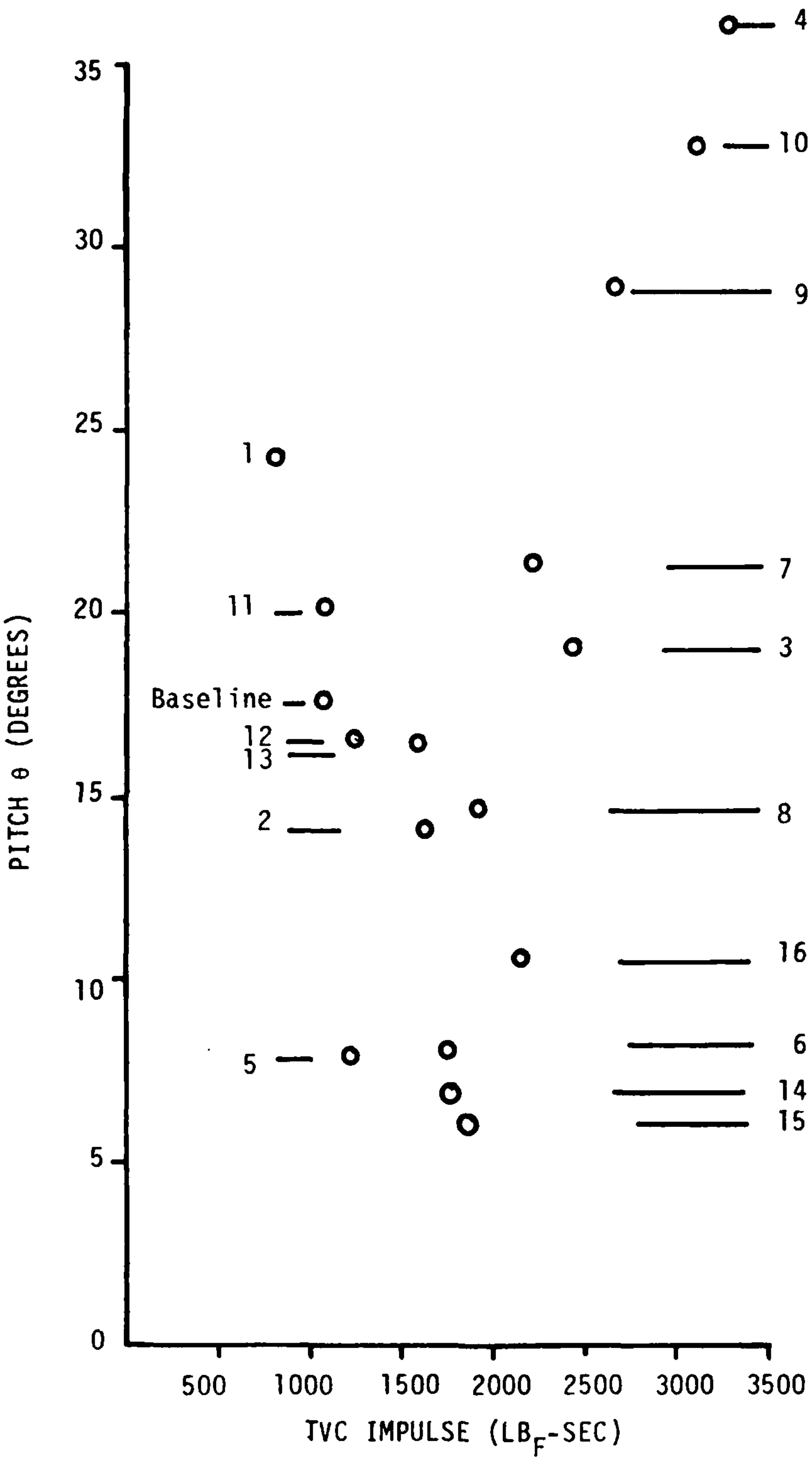


Figure 60. Model 1 Pitch vs Impulse

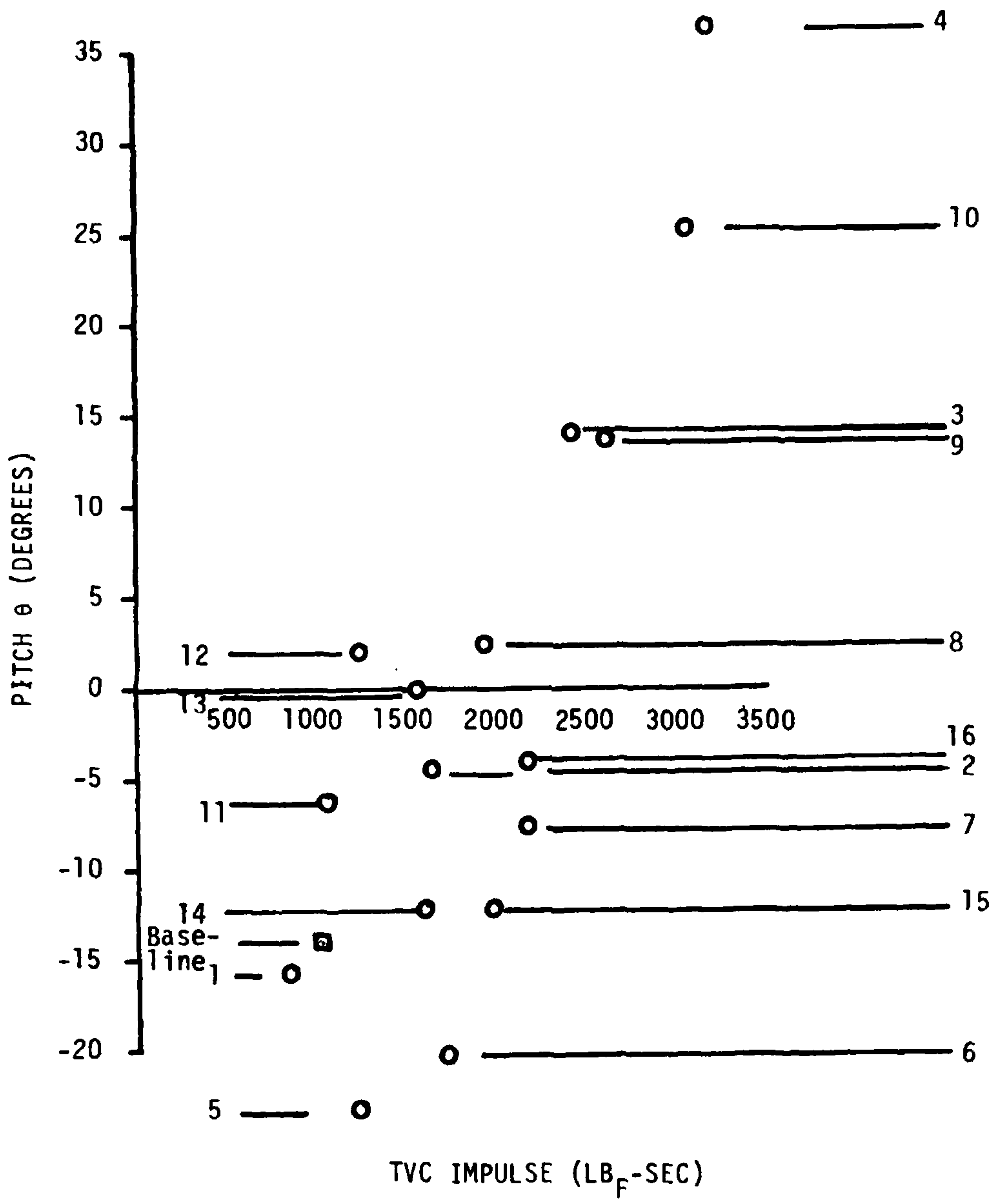


Figure 61. Model 2 Pitch vs Impulse

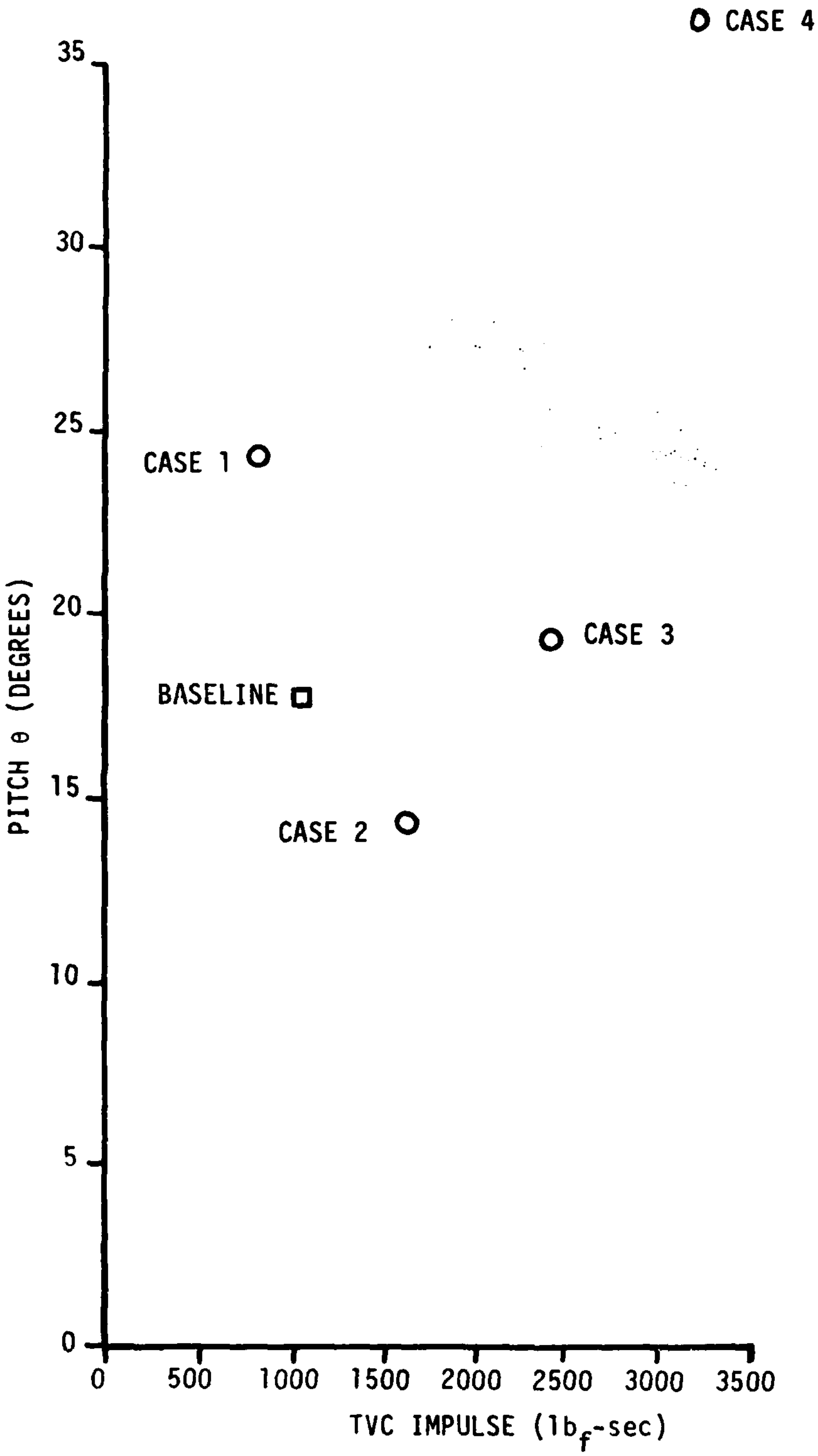


Figure 62. Model 1 Pitch vs Impulse

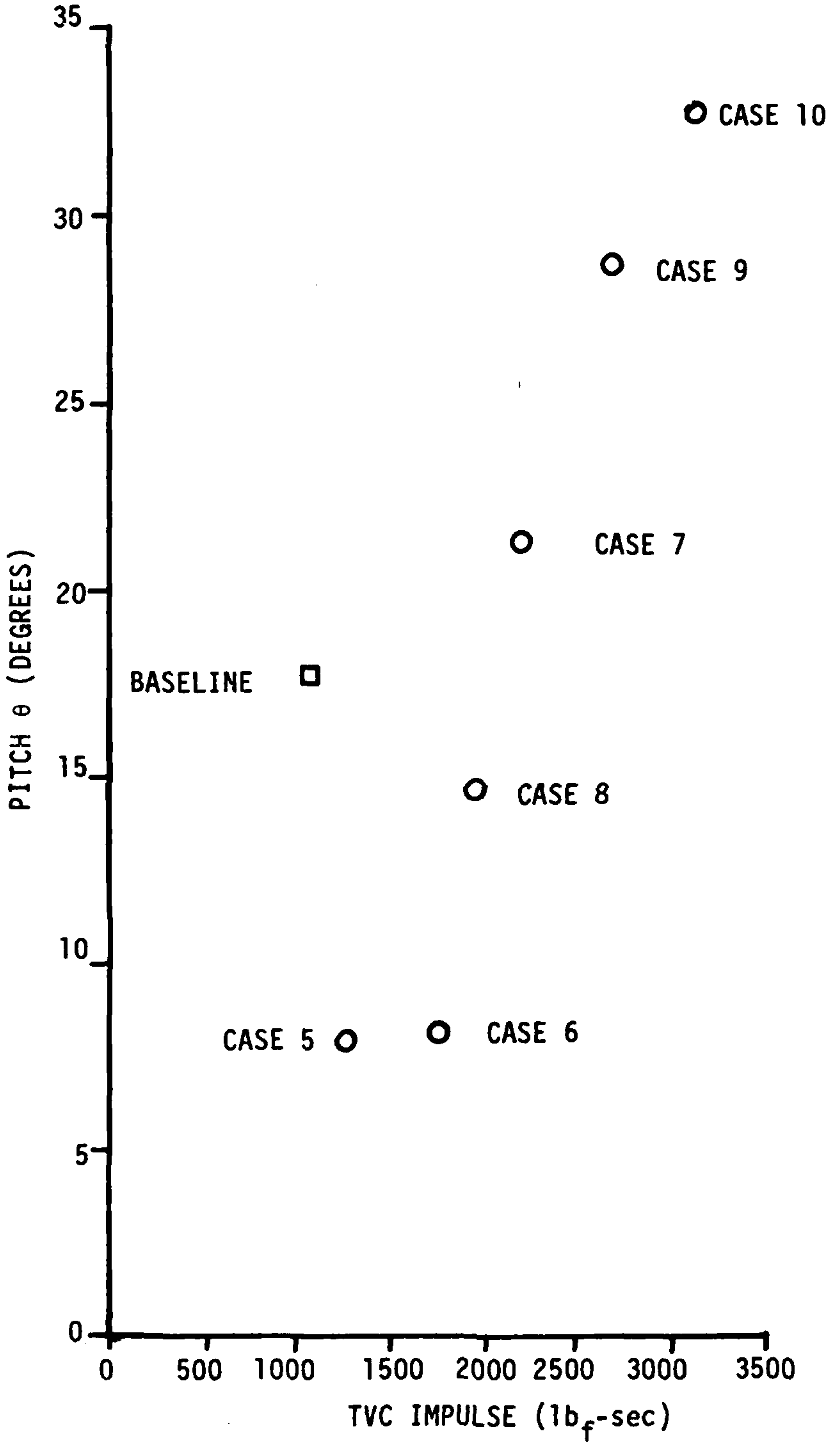


Figure 63. Model 1 Pitch vs Impulse

Figure 64. Model 1 Pitch vs Impulse

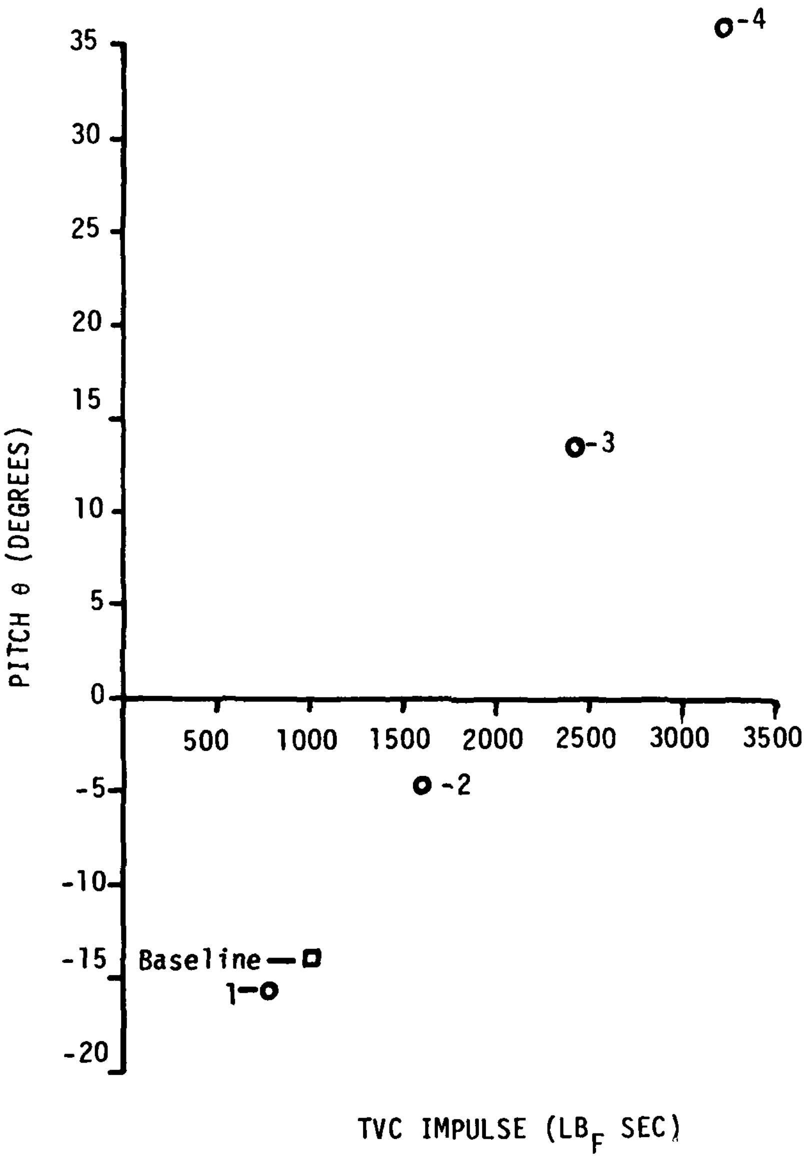


Figure 65. Model 2 Pitch vs Impulse

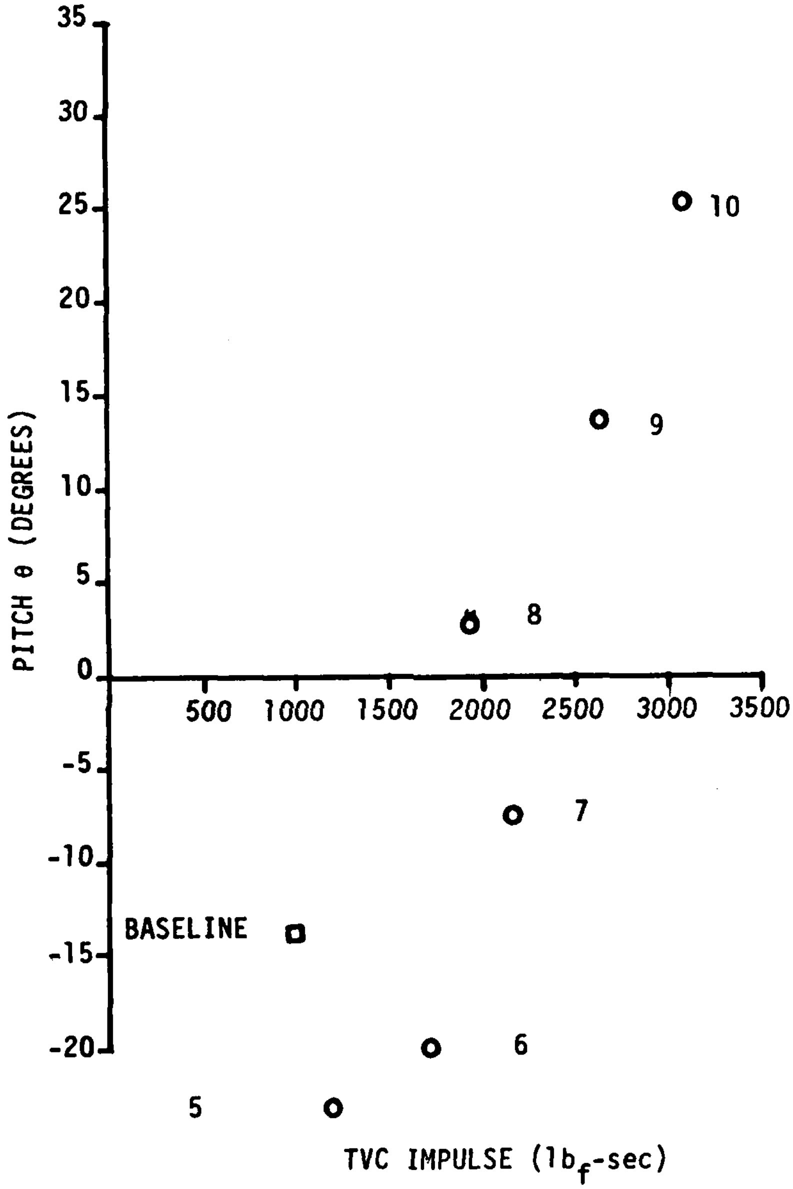


Figure 66. Model 2 Pitch vs Impulse

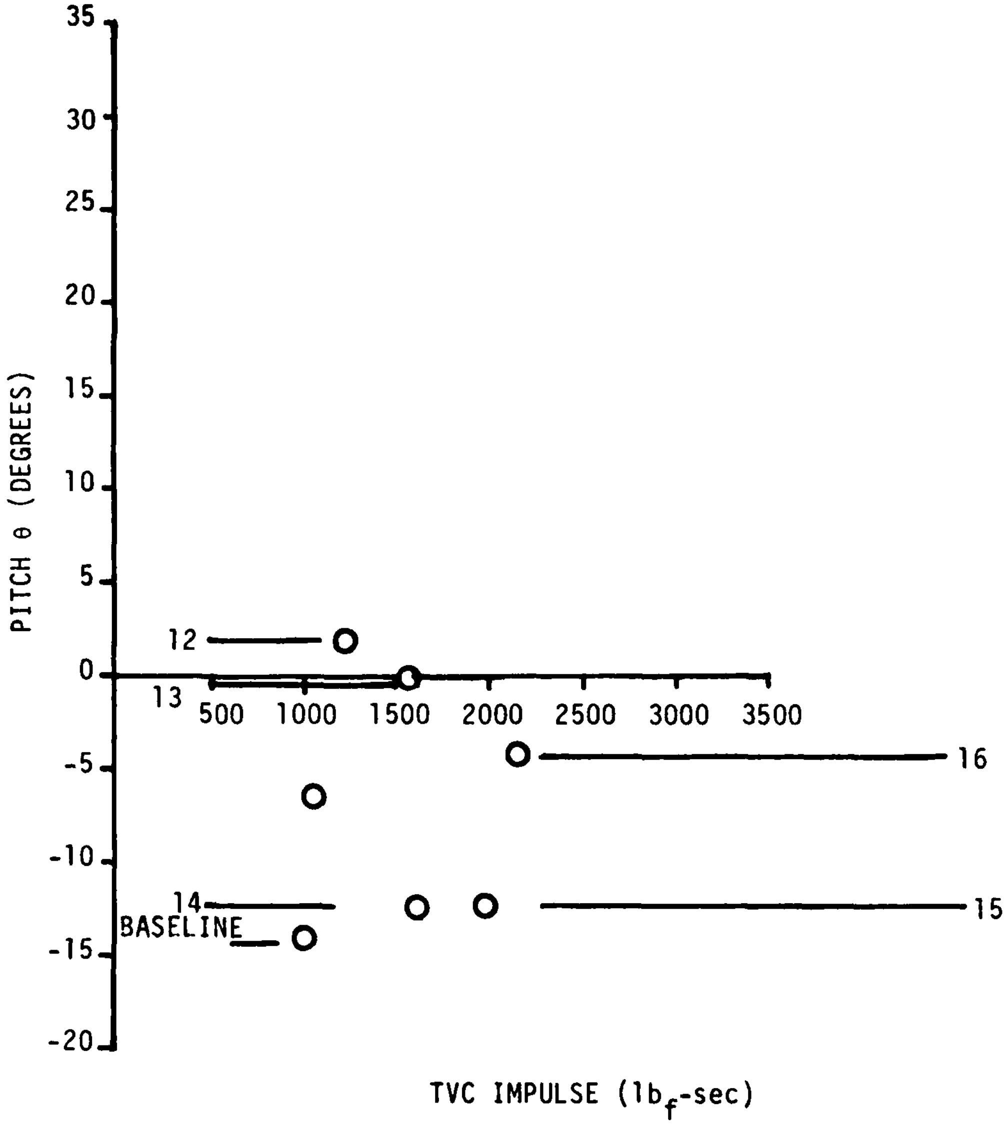


Figure 67. Model 2 Pitch vs Impulse

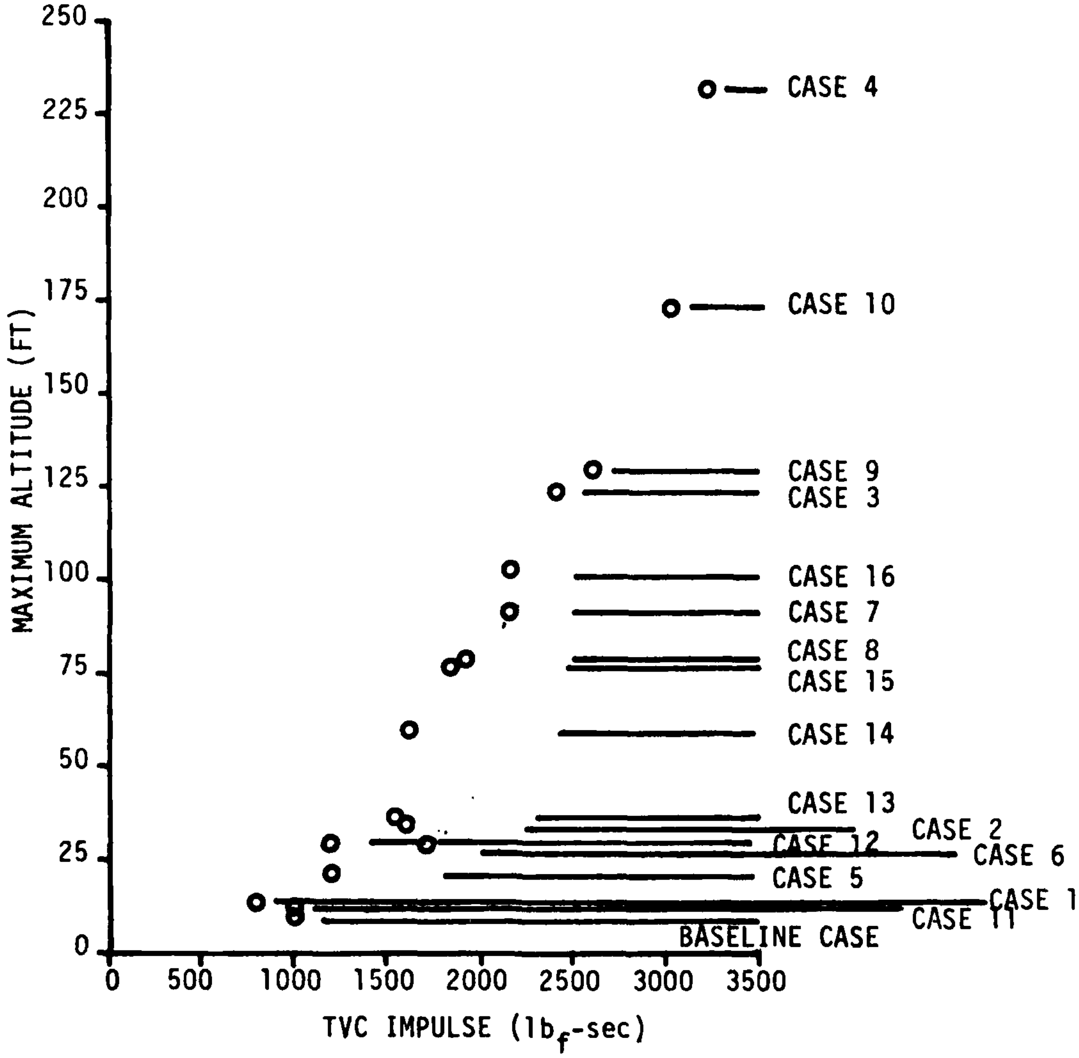


Figure 68. Model 1 Altitude vs Impulse

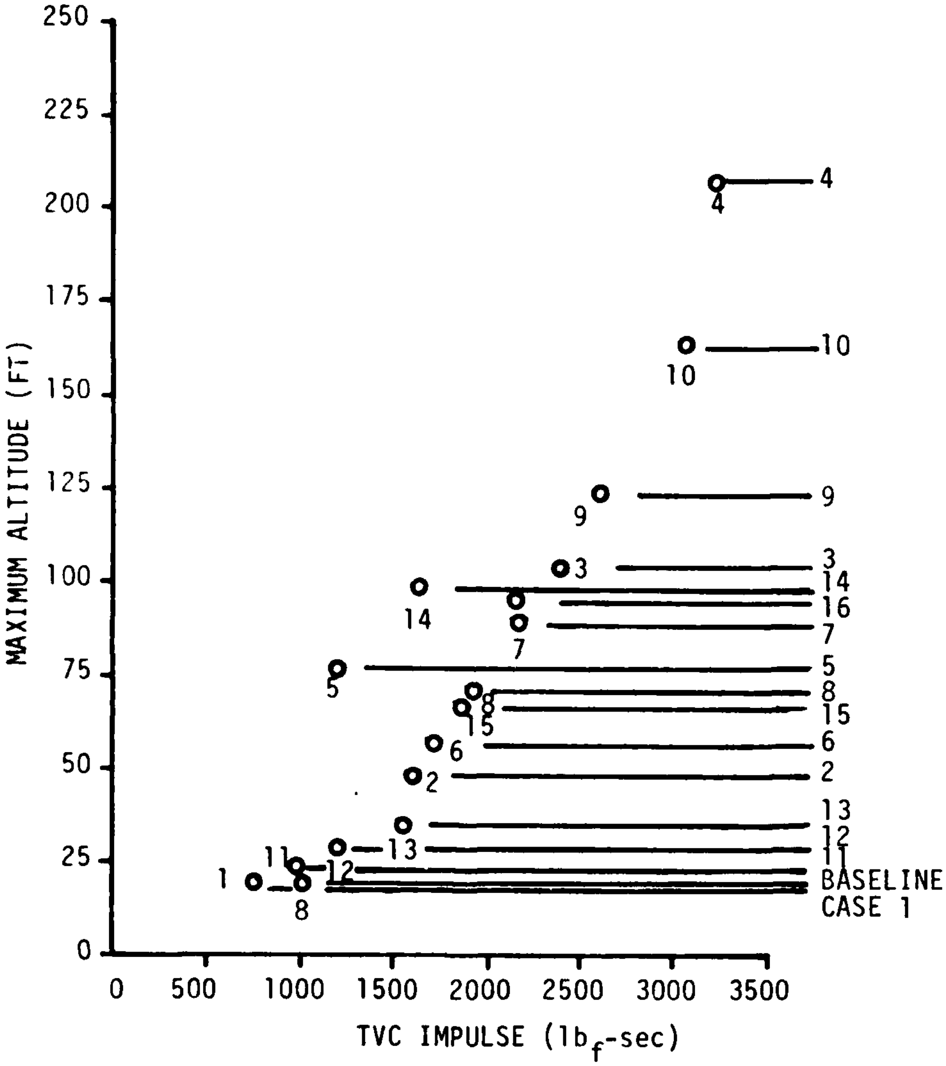


Figure 69. Model 2 Altitude vs Impulse

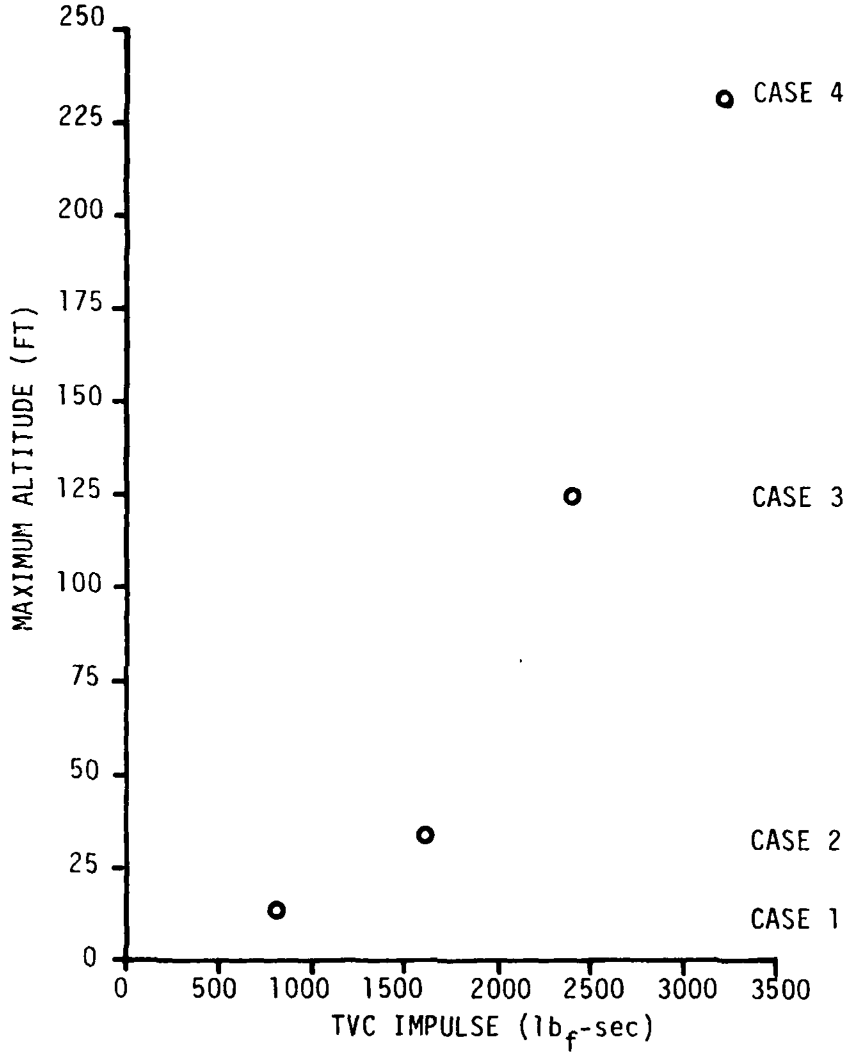


Figure 70. Model 1 Altitude vs Impulse

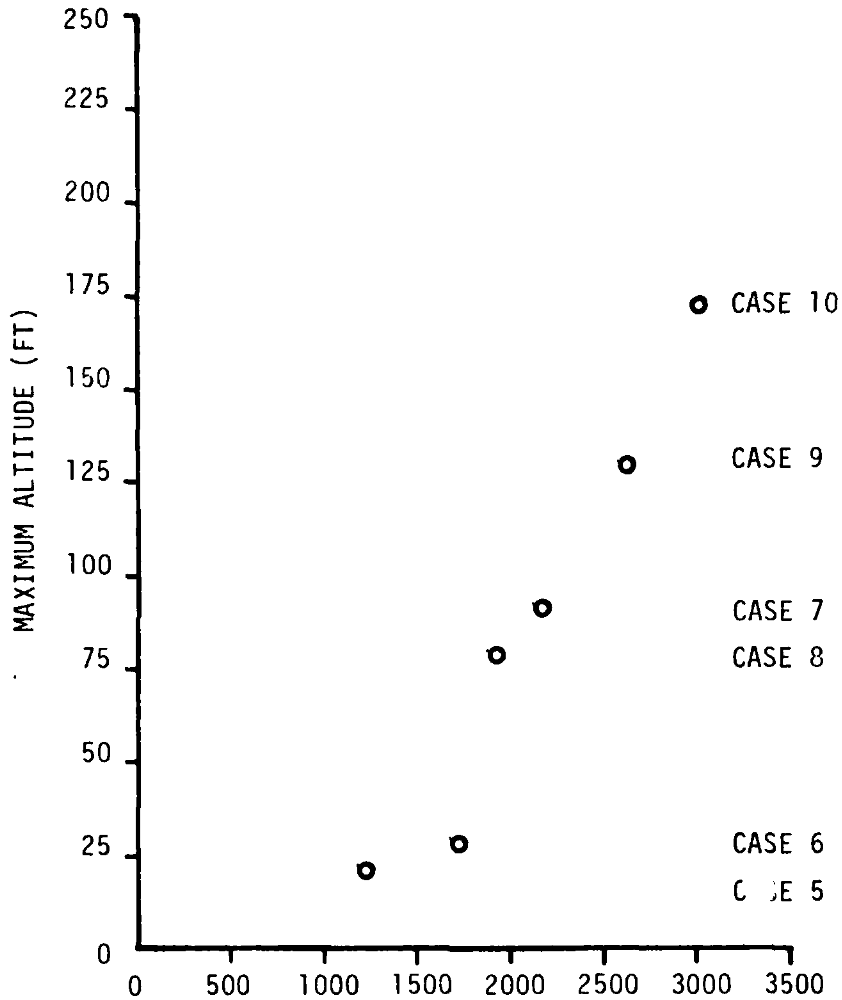


Figure 71. Model 1 Altitude vs Impulse

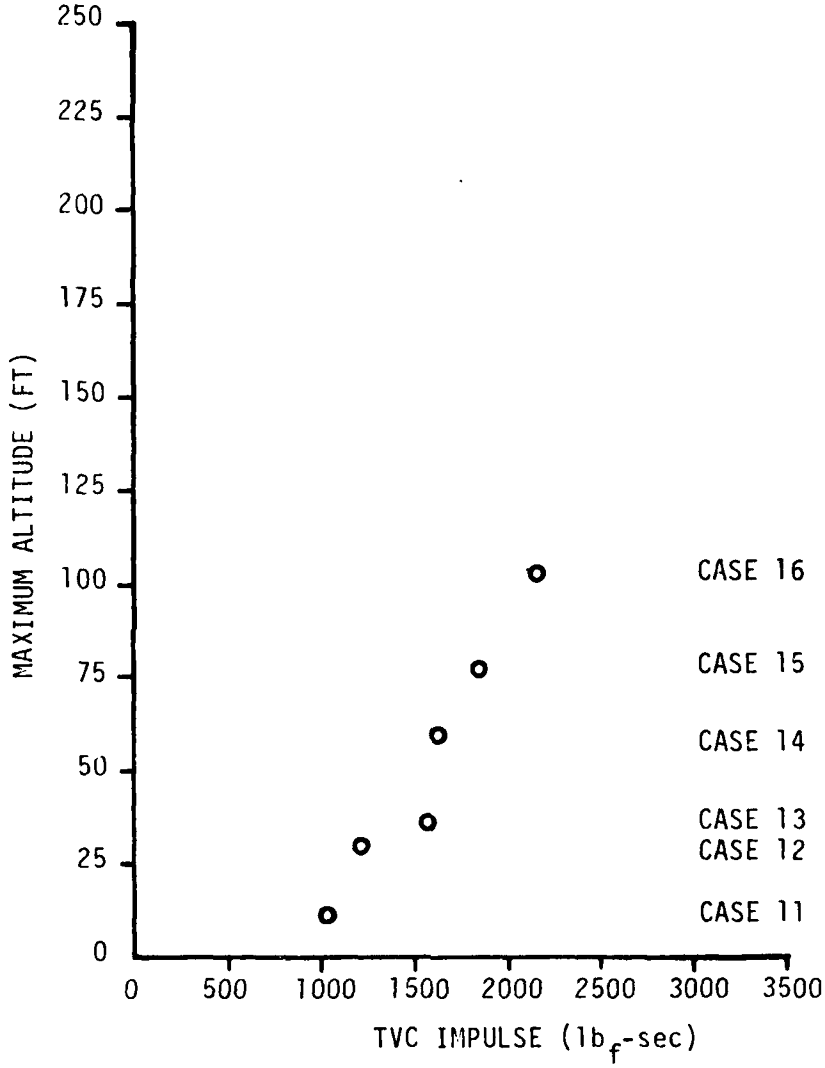


Figure 72. Model 1 Altitude vs Impulse

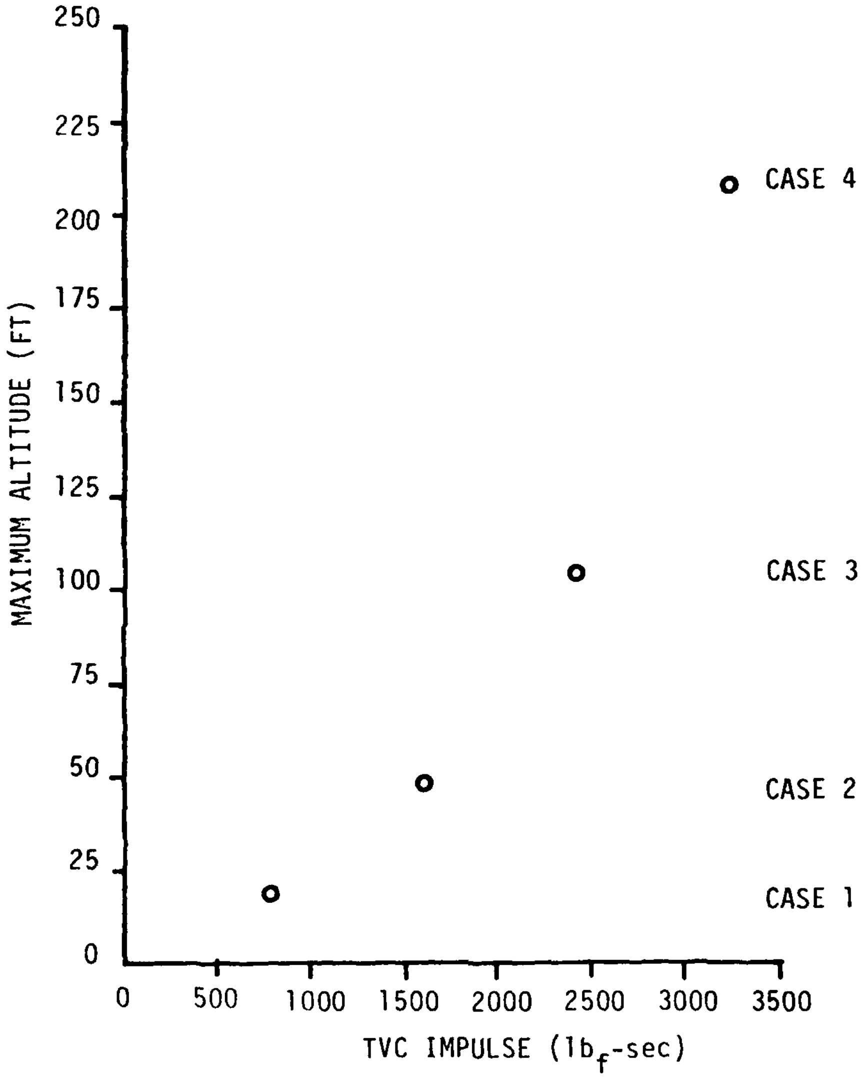


Figure 73. Model 2 Altitude vs Impulse

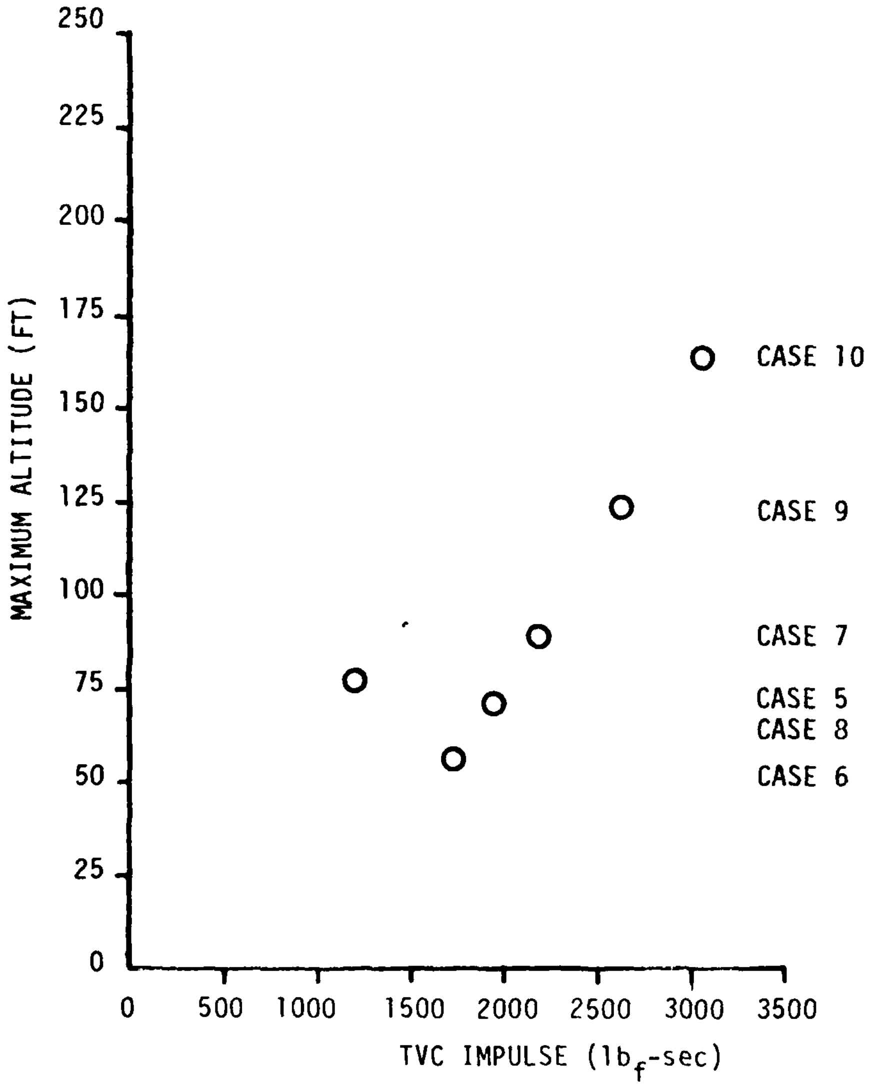


Figure 74. Model 2 Altitude vs Impulse

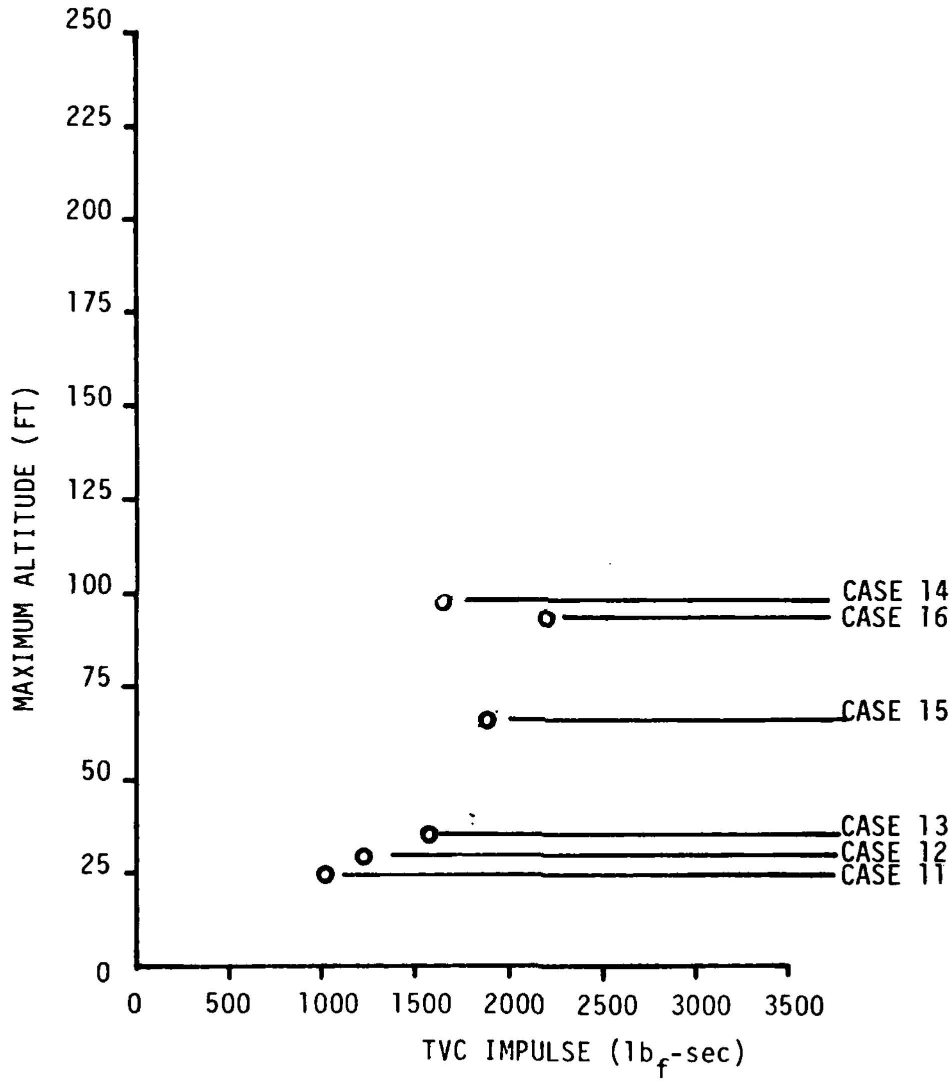


Figure 75. Model 2 Altitude vs Impulse

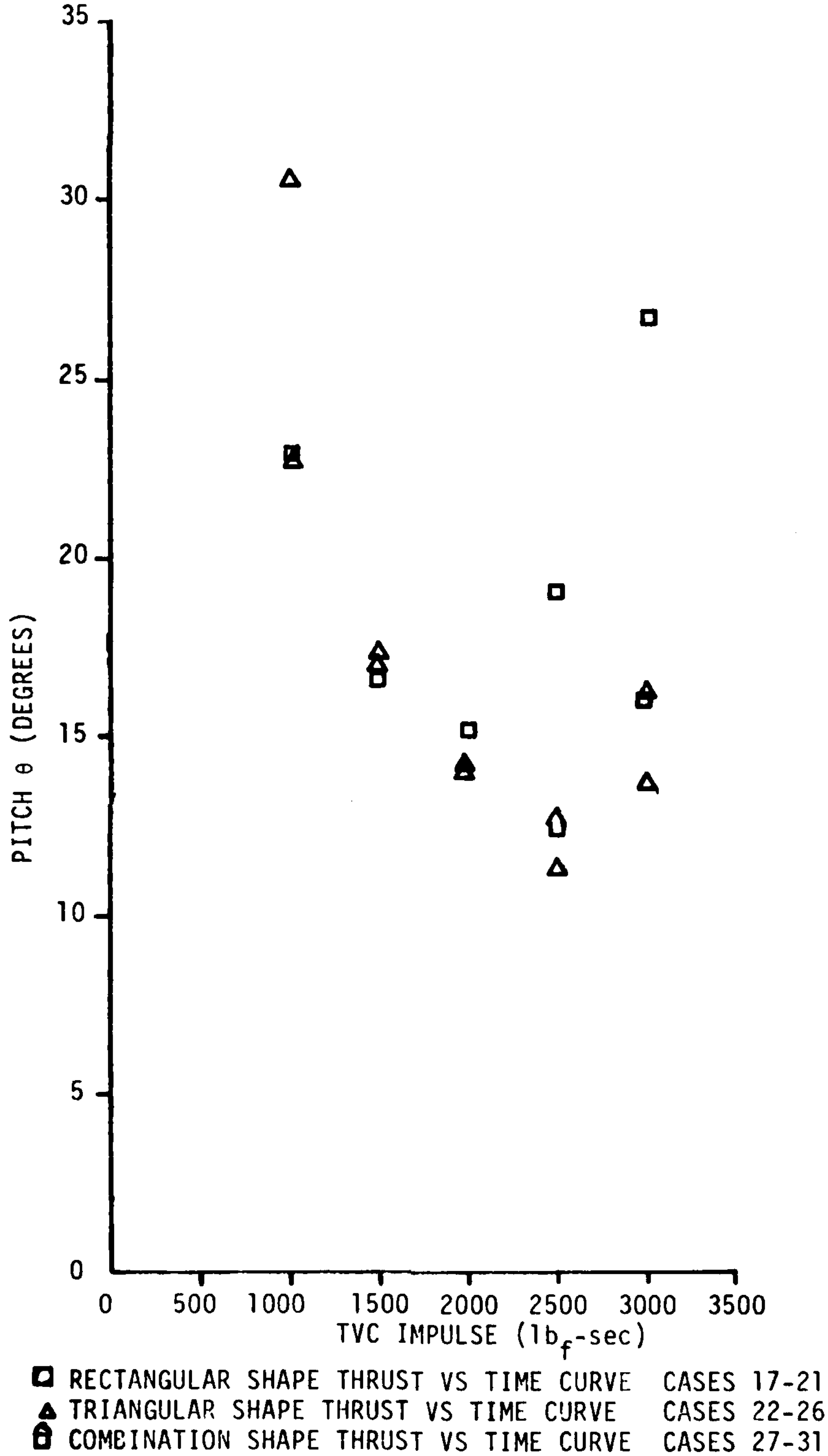


Figure 76. Model 1 Pitch vs Impulse

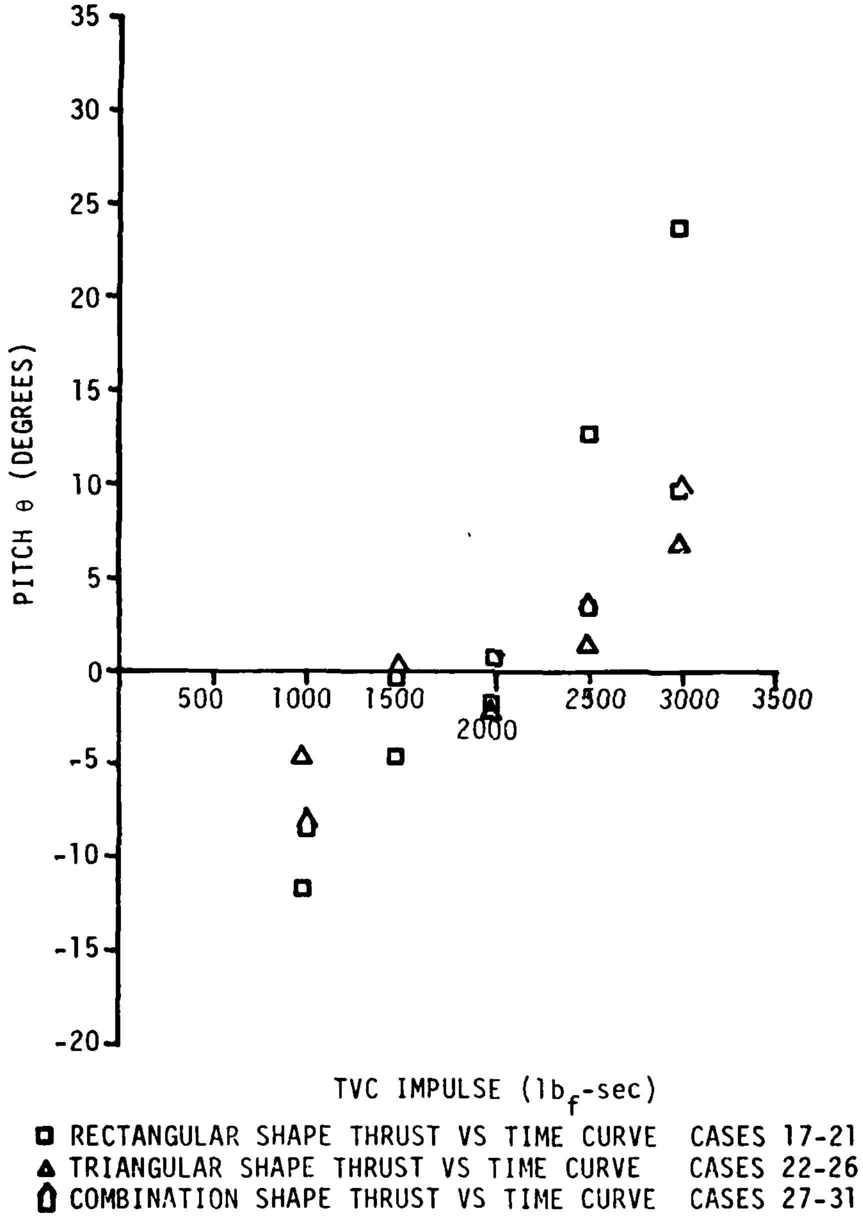


Figure 77. Model 2 Pitch vs Impulse

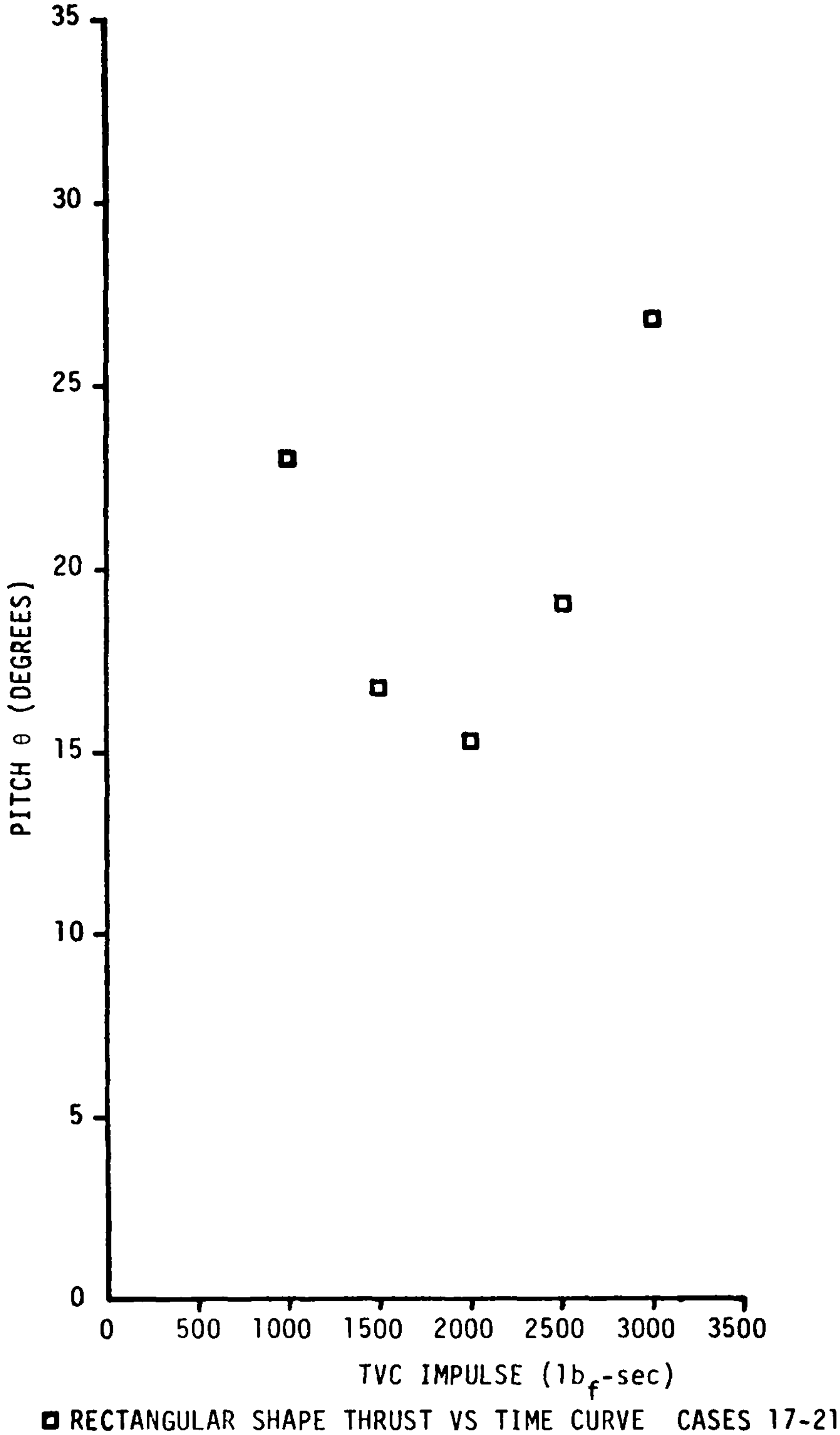


Figure 78. Model 1 Pitch vs Impulse

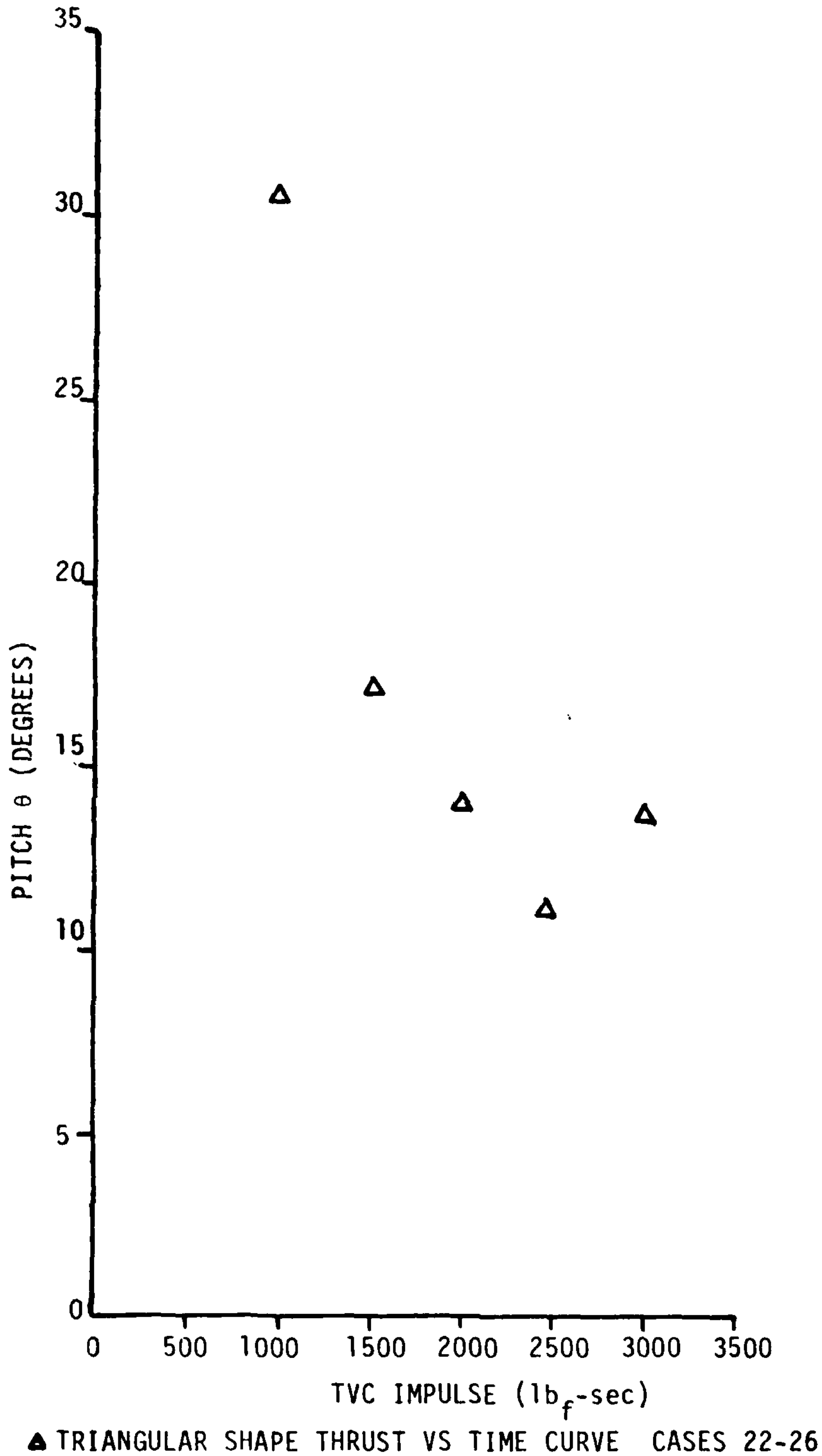


Figure 79. Model 1 Pitch vs Impulse

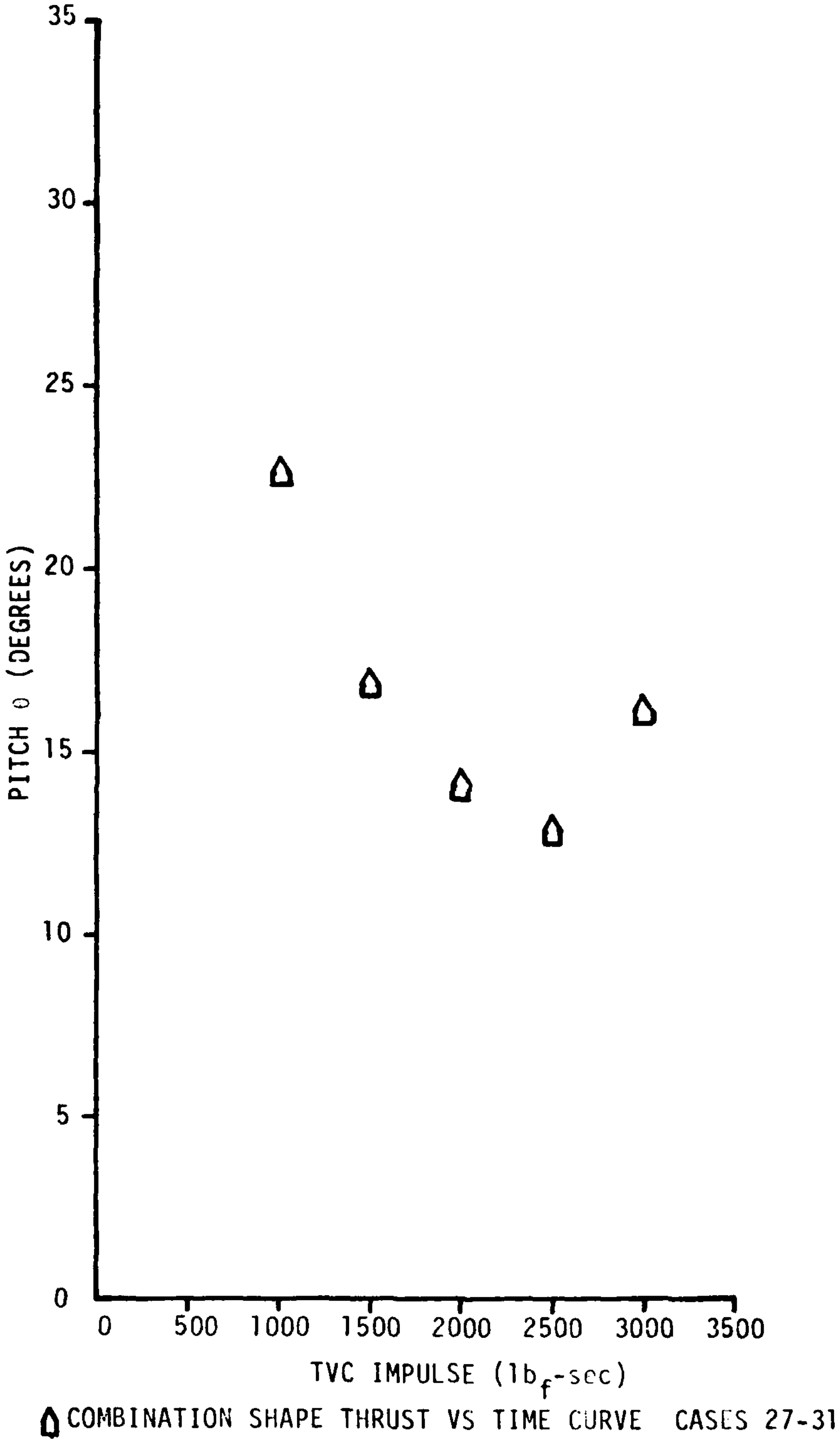


Figure 80. Model 1 Pitch vs Impulse

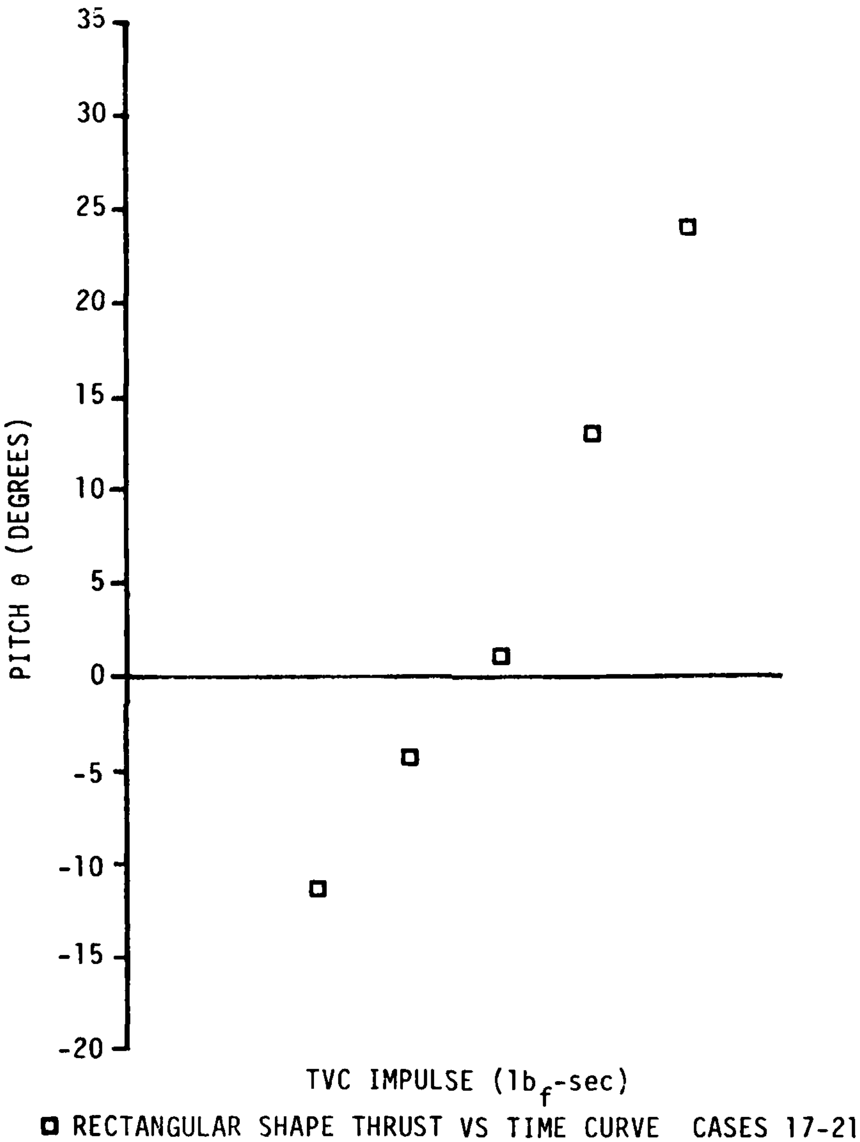


Figure 81. Model 2 Pitch vs Impulse

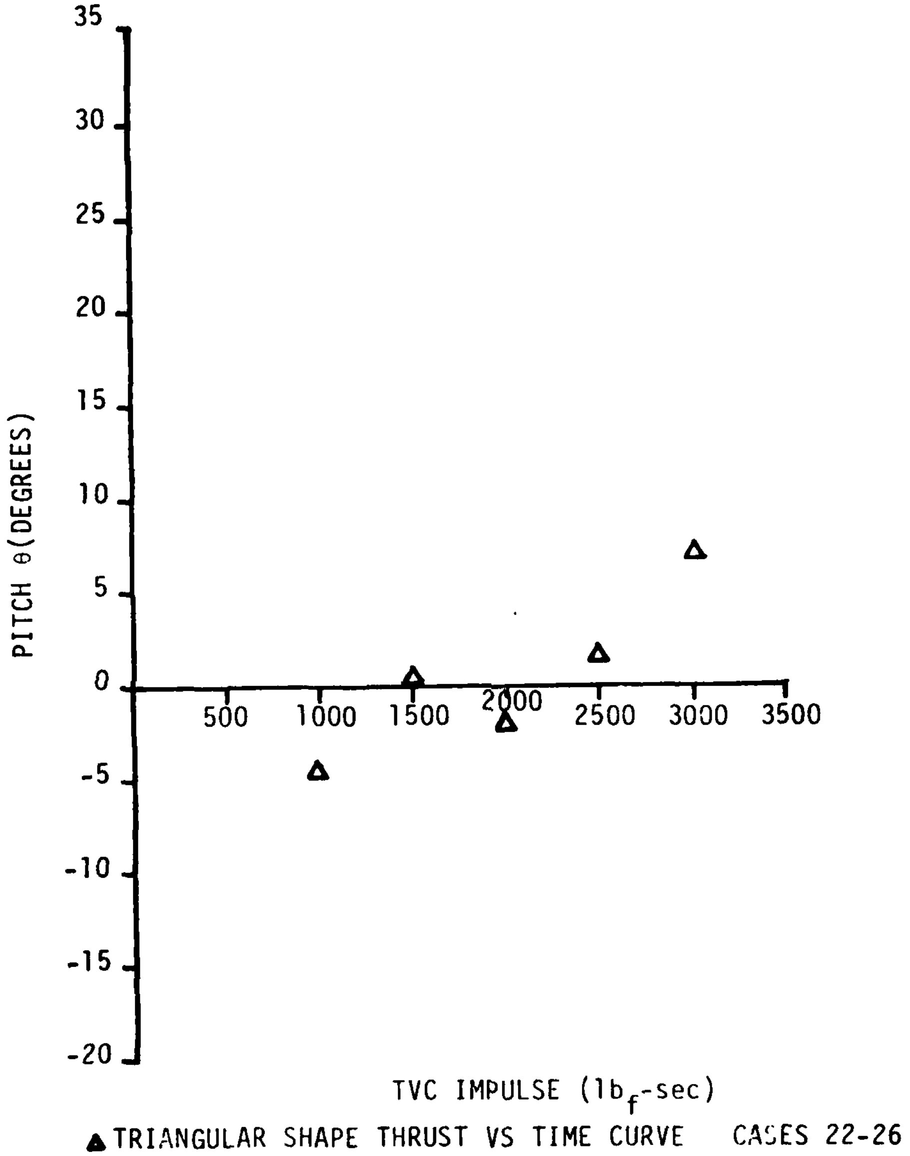


Figure 82. Model 2 Pitch vs Impulse

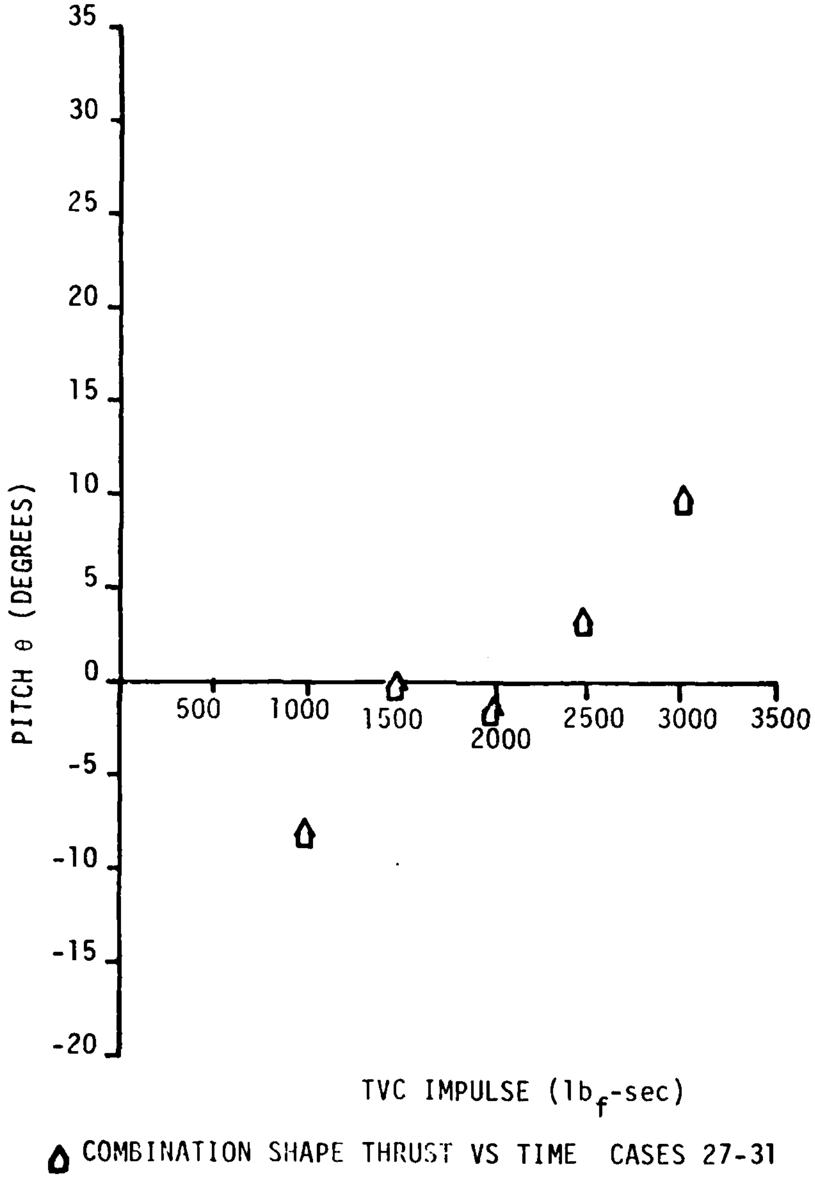
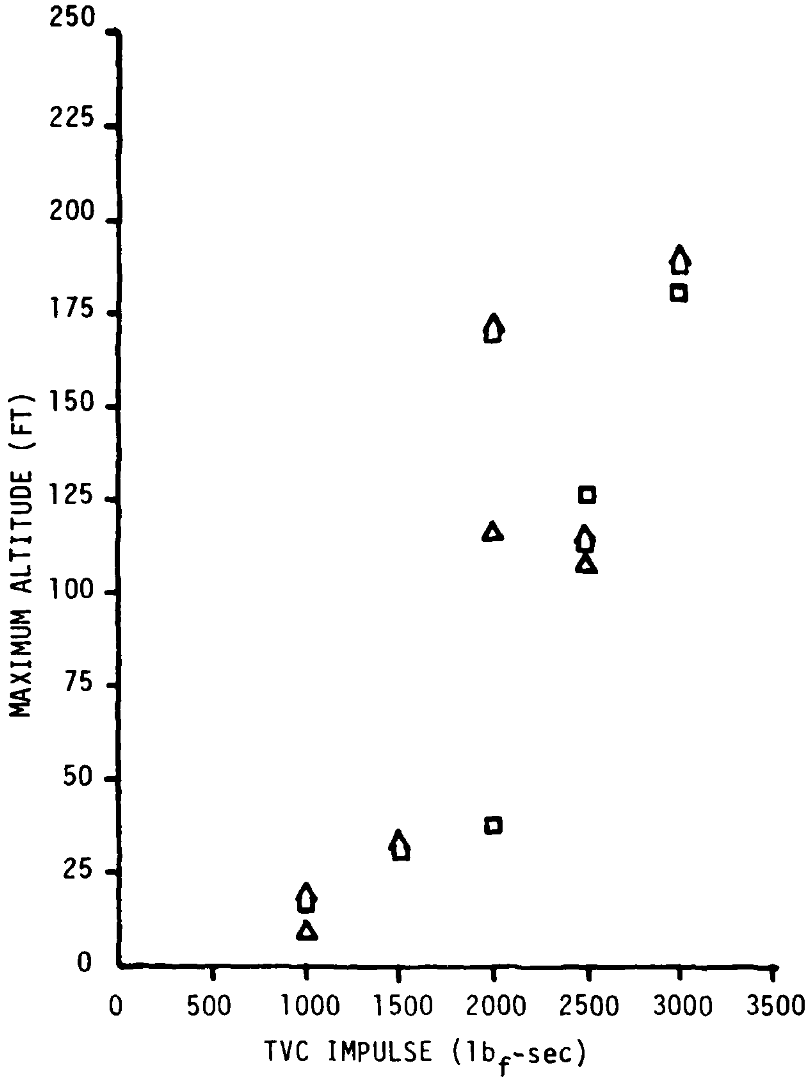


Figure 83. Model 2 Pitch vs Impulse



□ RECTANGULAR SHAPE THRUST VS TIME CURVE CASES 17-21
△ TRIANGULAR SHAPE THRUST VS TIME CURVE CASES 22-26
COMBINATION SHAPE THRUST VS TIME CURVE CASES 27-31

Figure 34. Model 1 Altitude vs Impulse

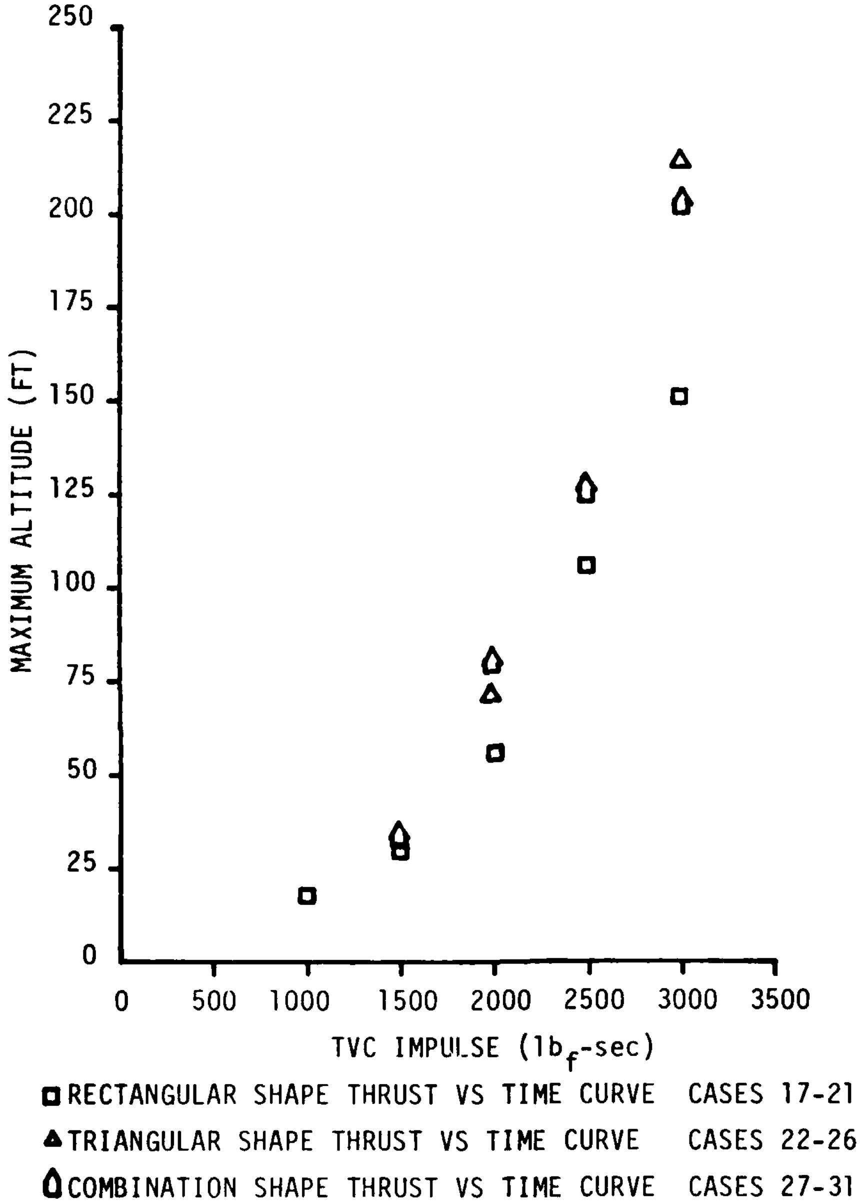


Figure 85. Model 2 Altitude vs Impulse

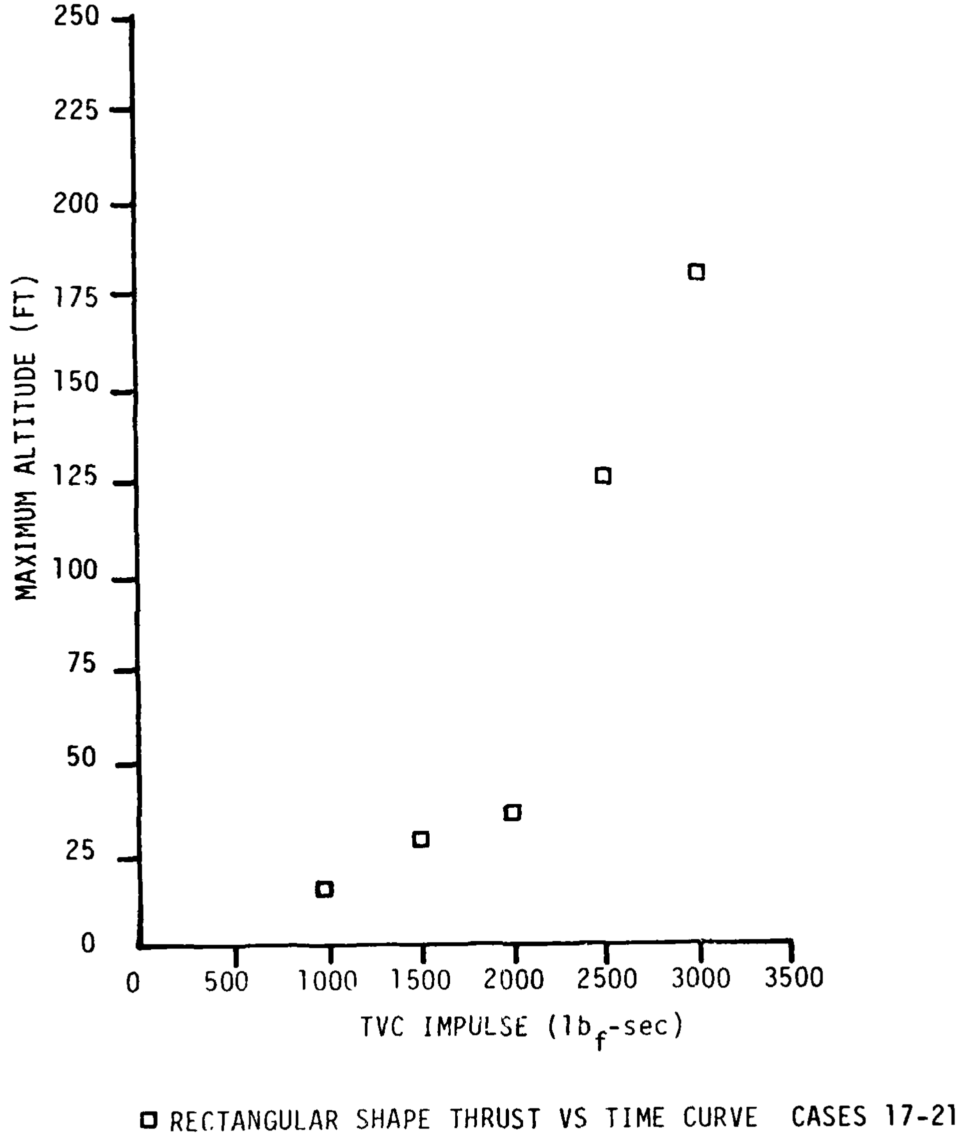


Figure 86. Model 1 Altitude vs Impulse

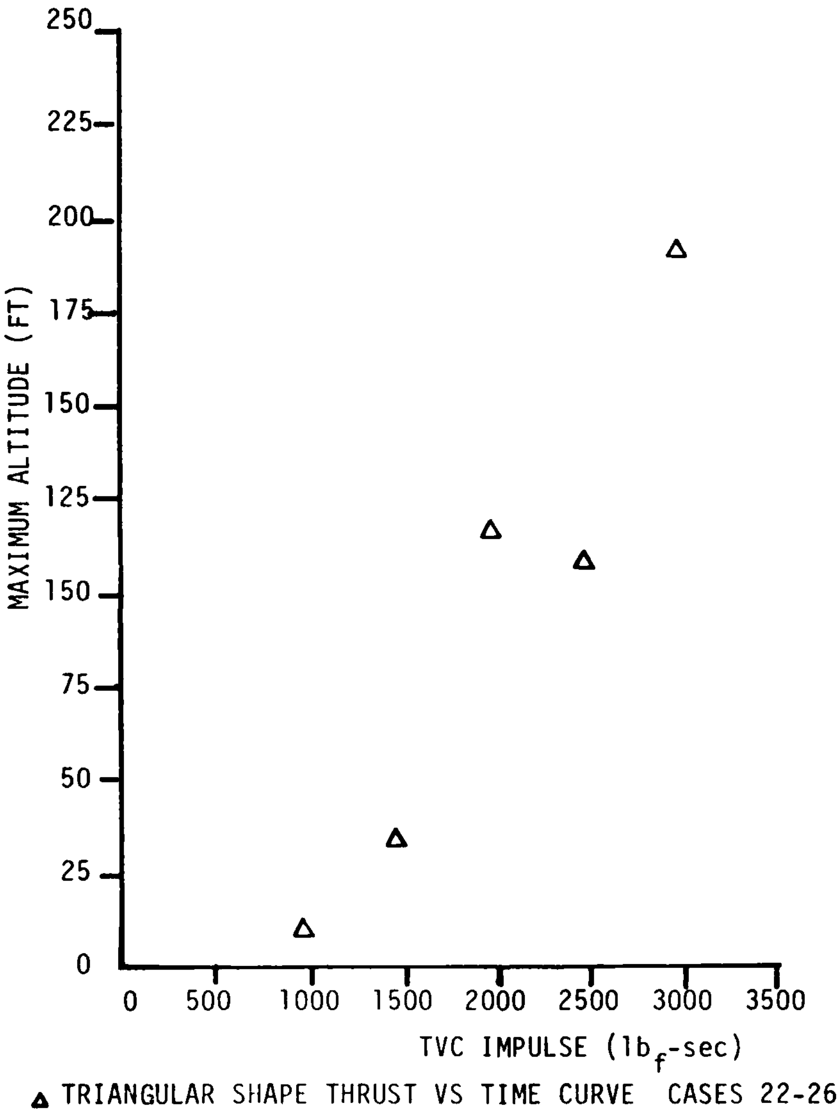


Figure 87. Model 1 Altitude vs Impulse

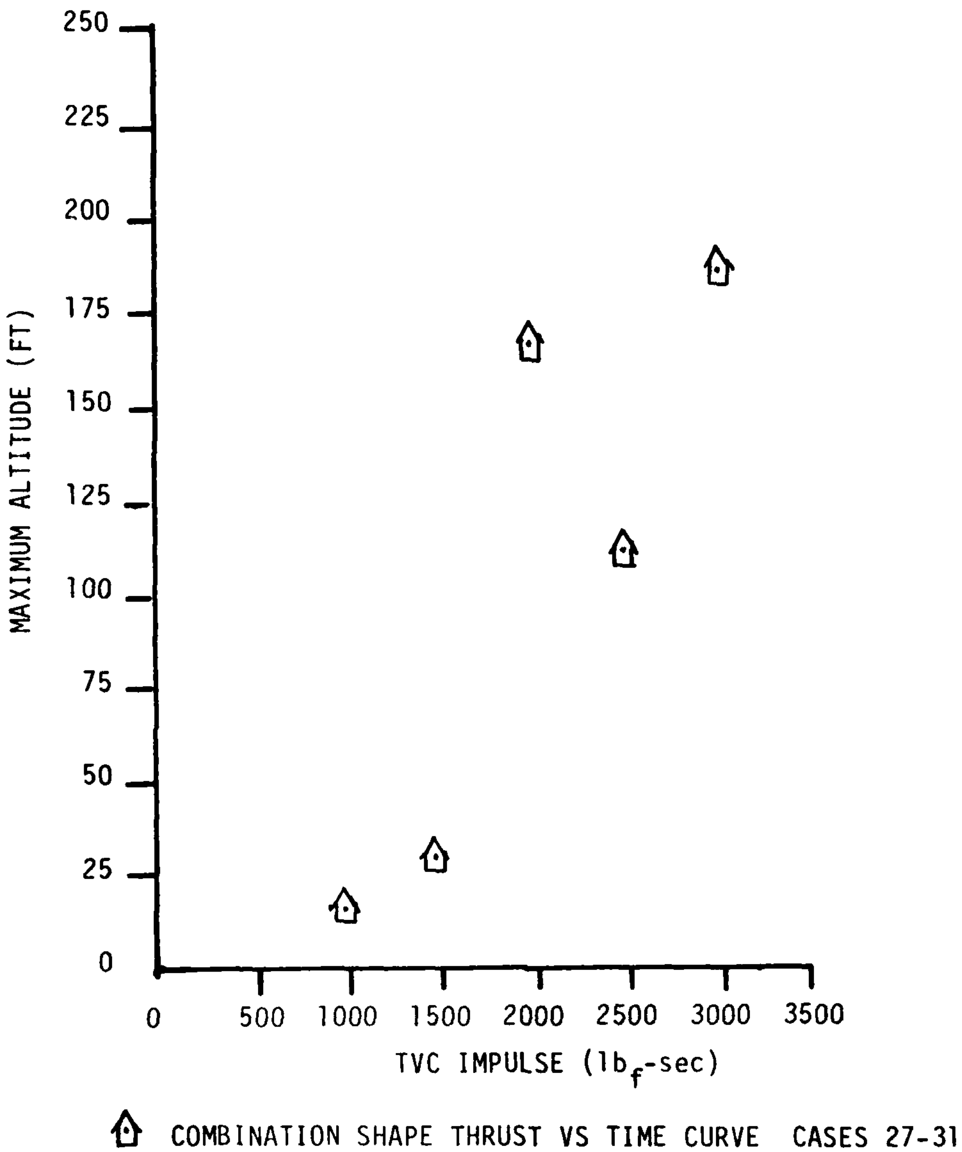


Figure 88. Model 1 Altitude vs Impulse

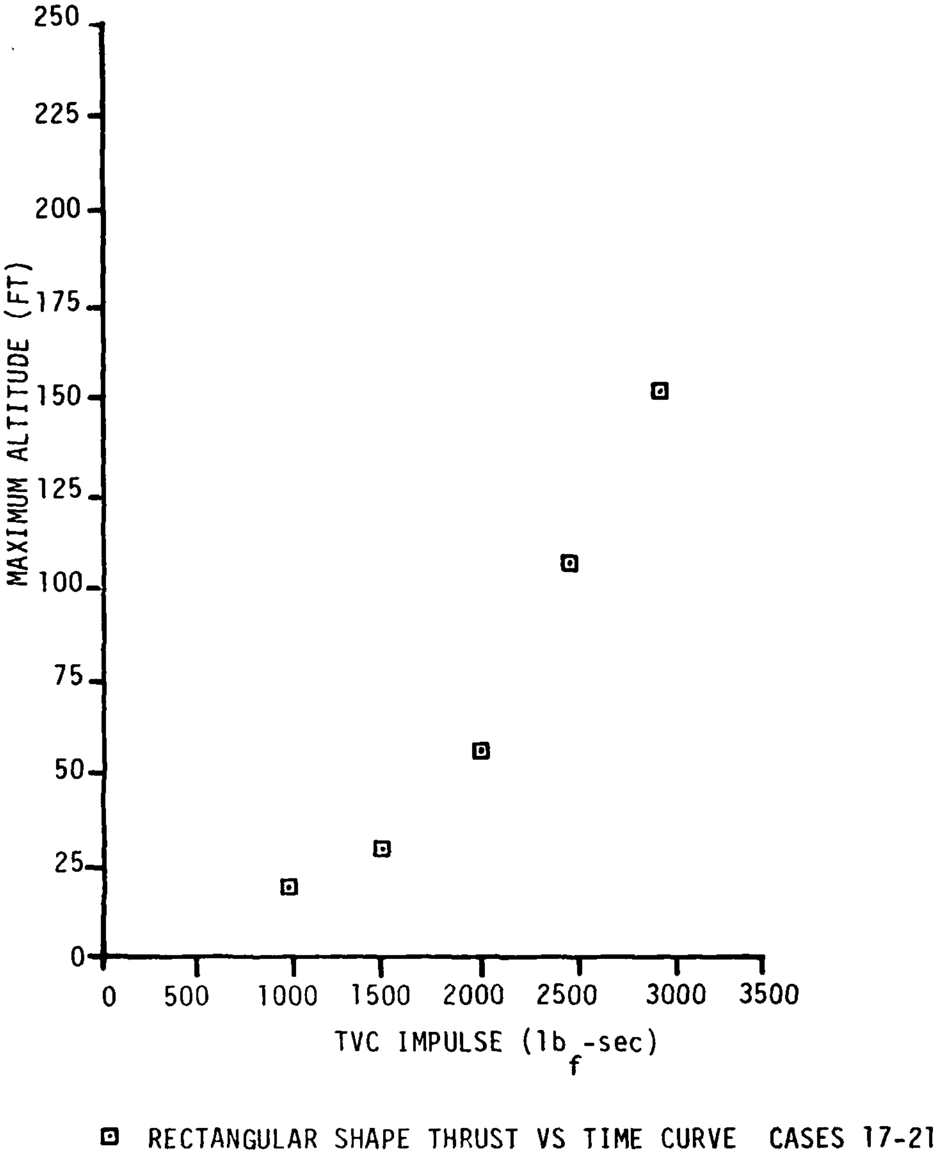


Figure 89. Model 2 Altitude vs Impulse

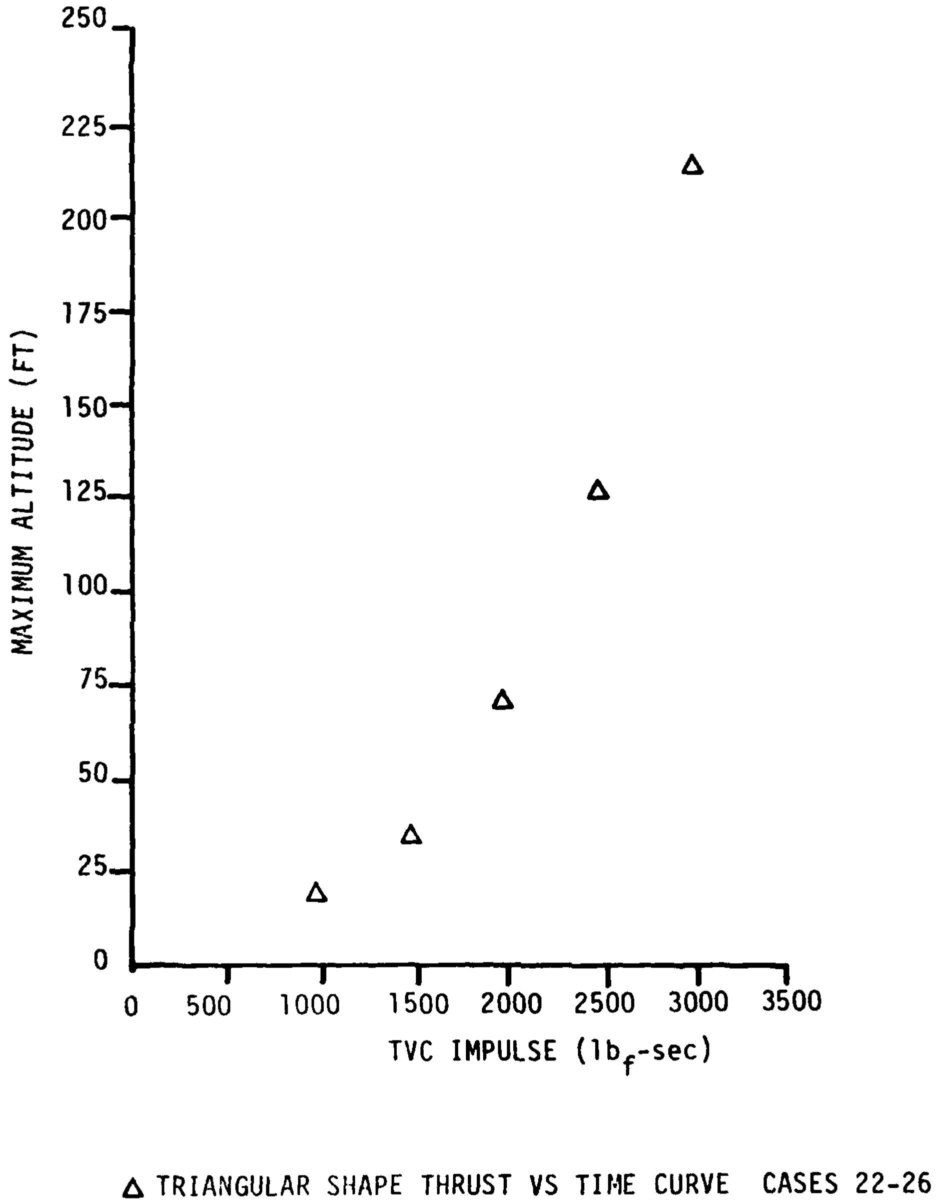


Figure 90. Model 2 Altitude vs Impulse

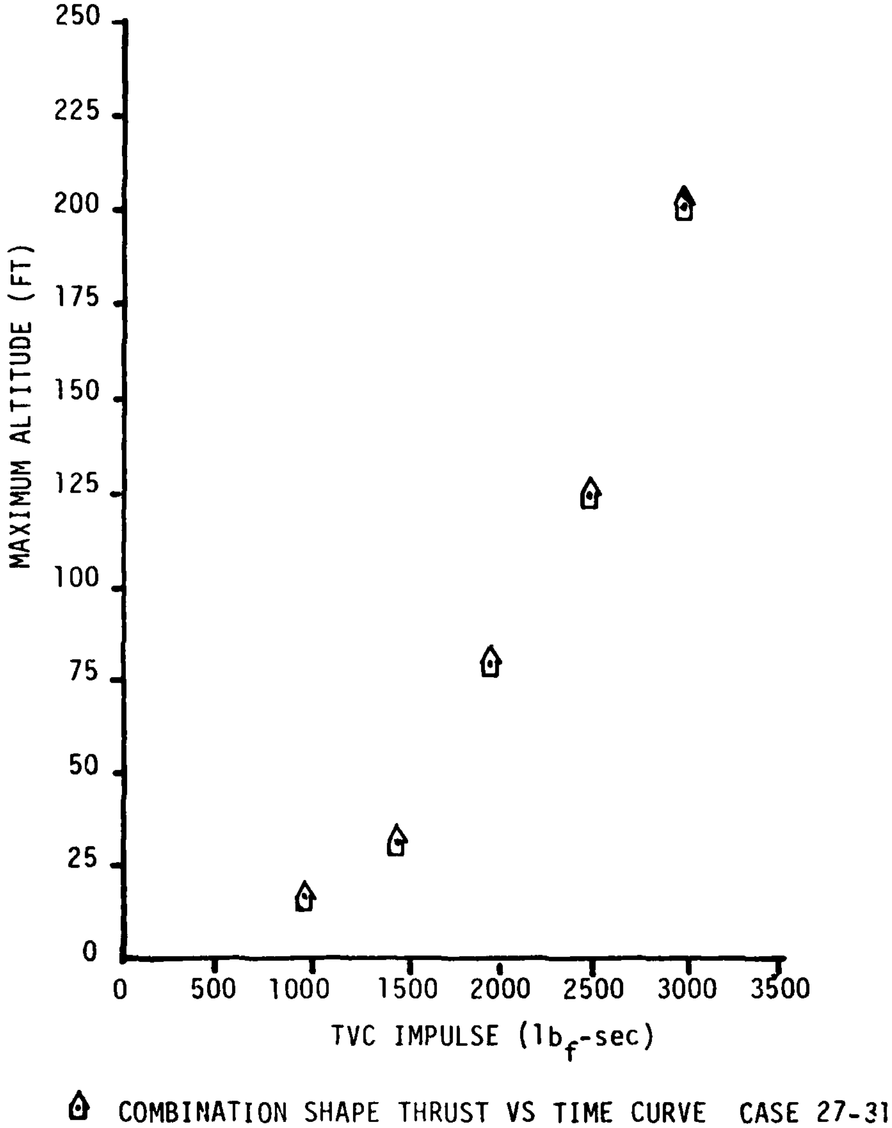


Figure 91. Model 2 Altitude vs Impulse

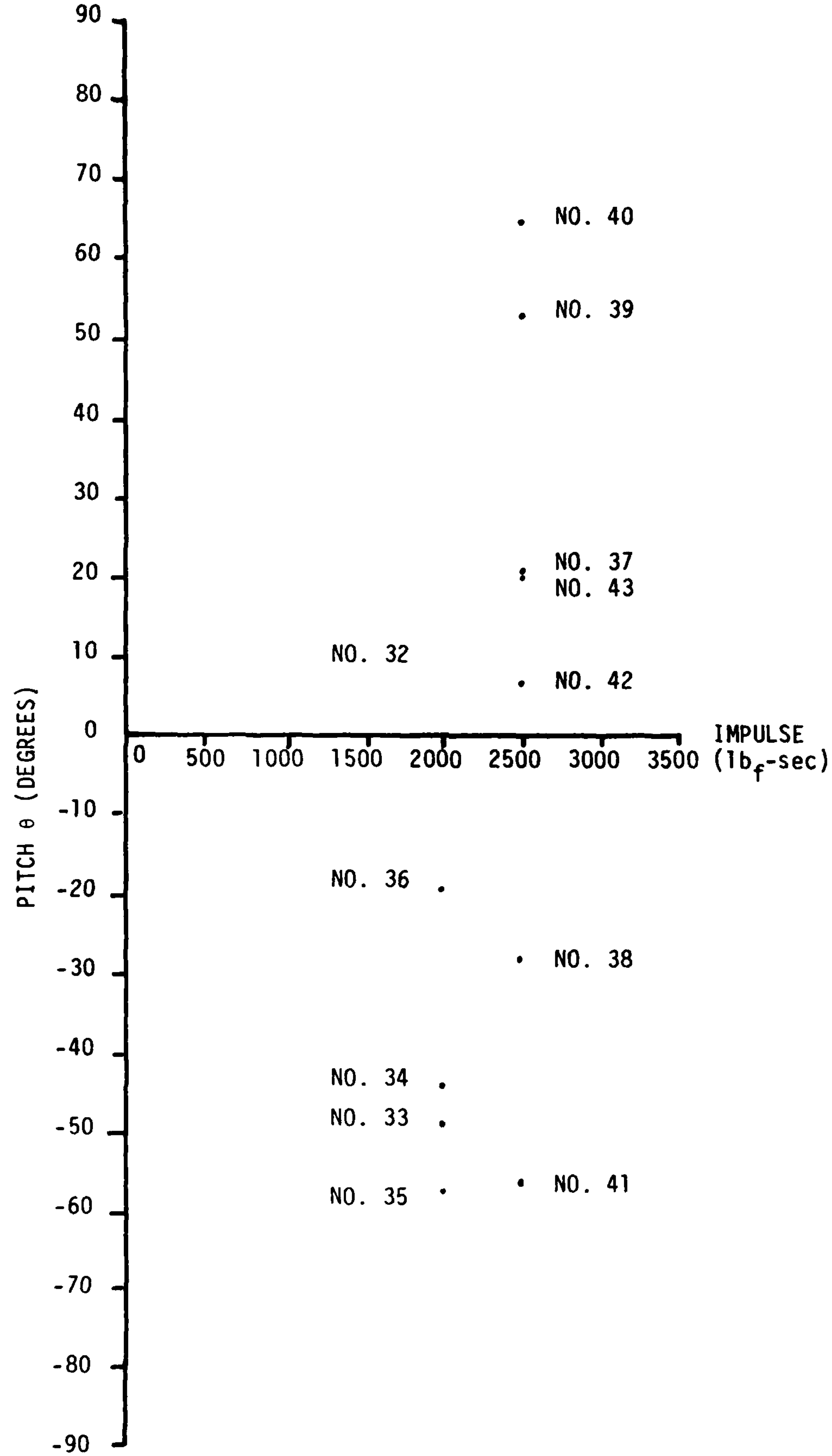


Figure 92. Model 1 Pitch vs Impulse

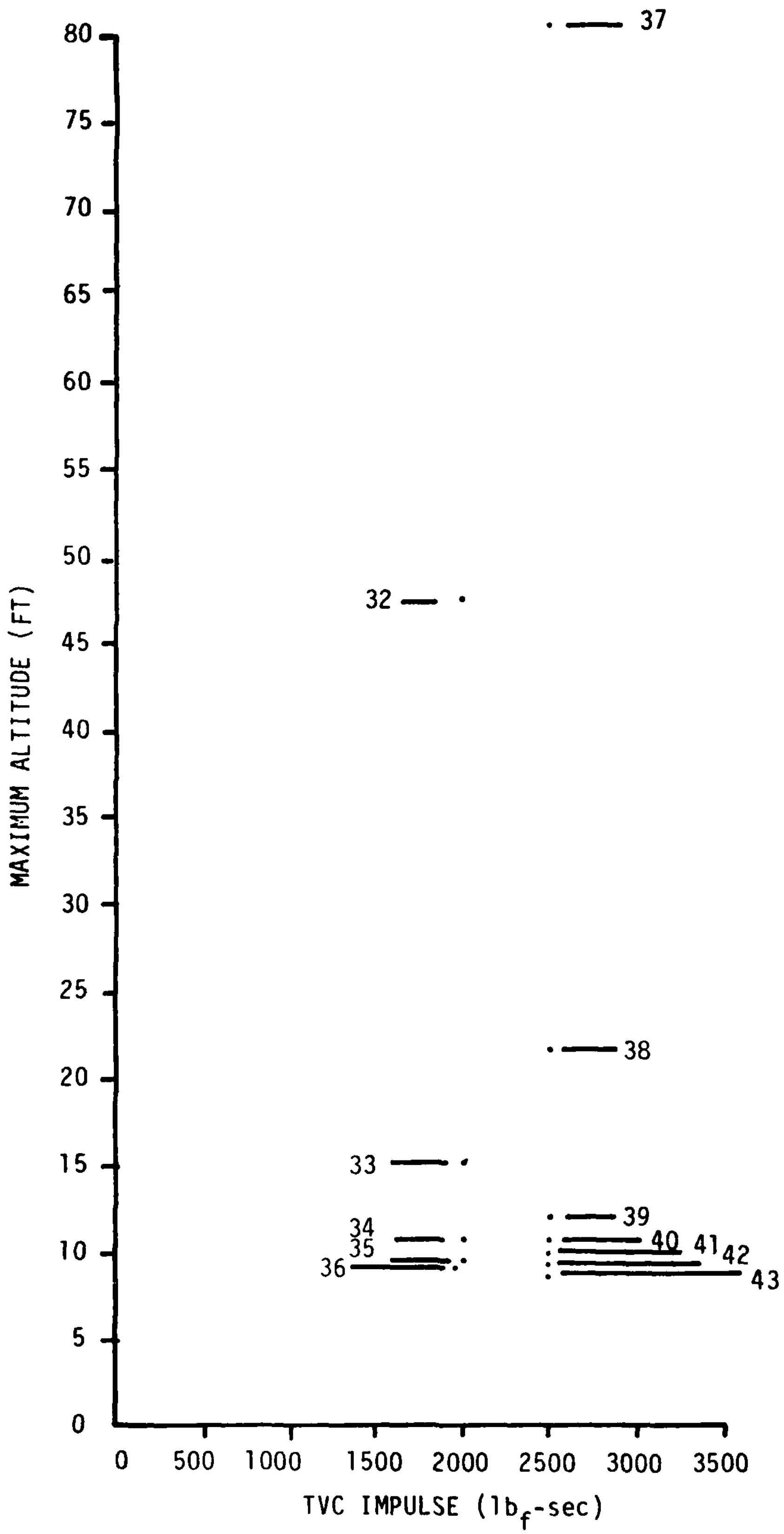


Figure 93. Model 1 Altitude vs Impulse

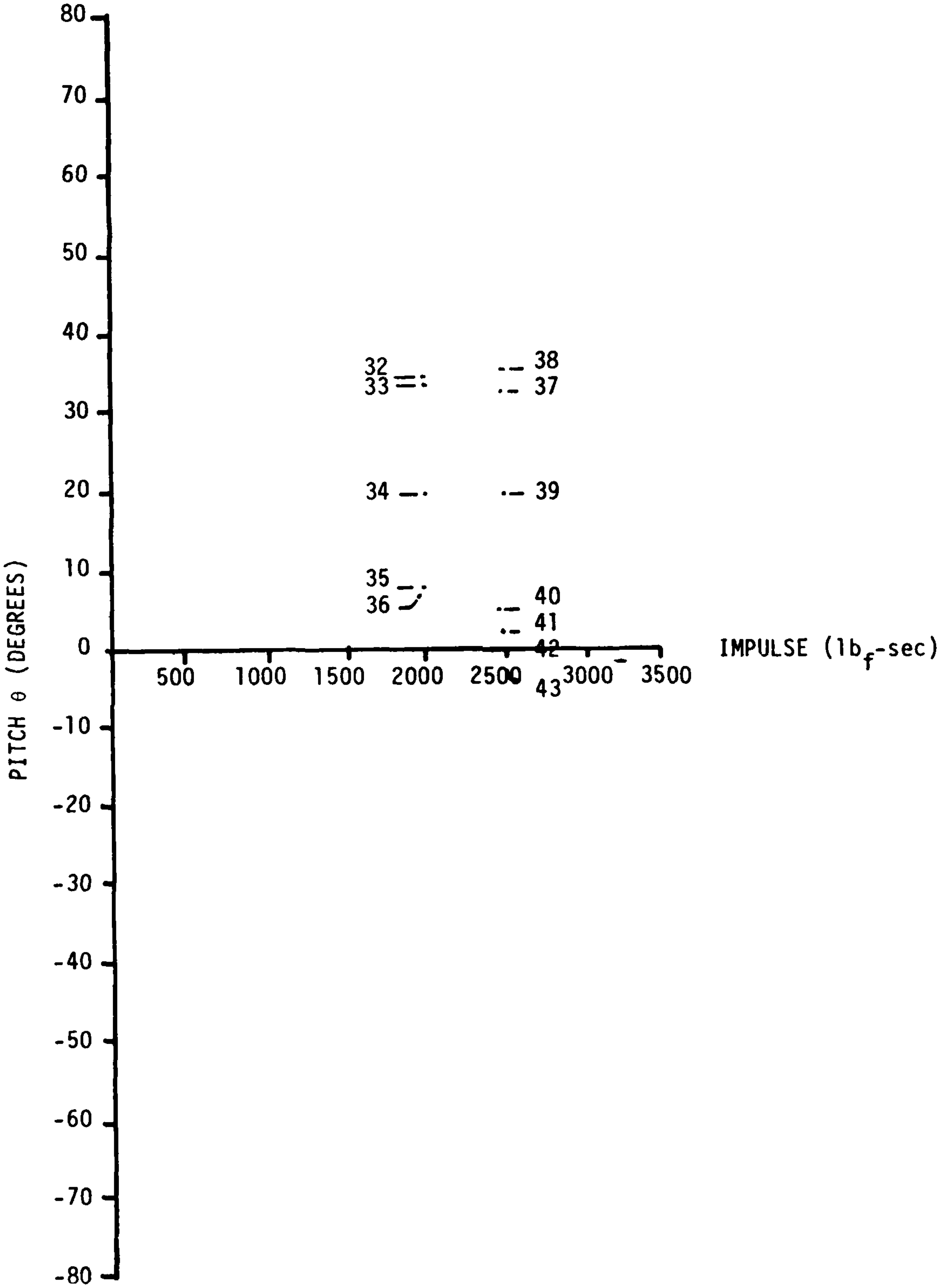


Figure 94. Model 2 Pitch vs Impulse

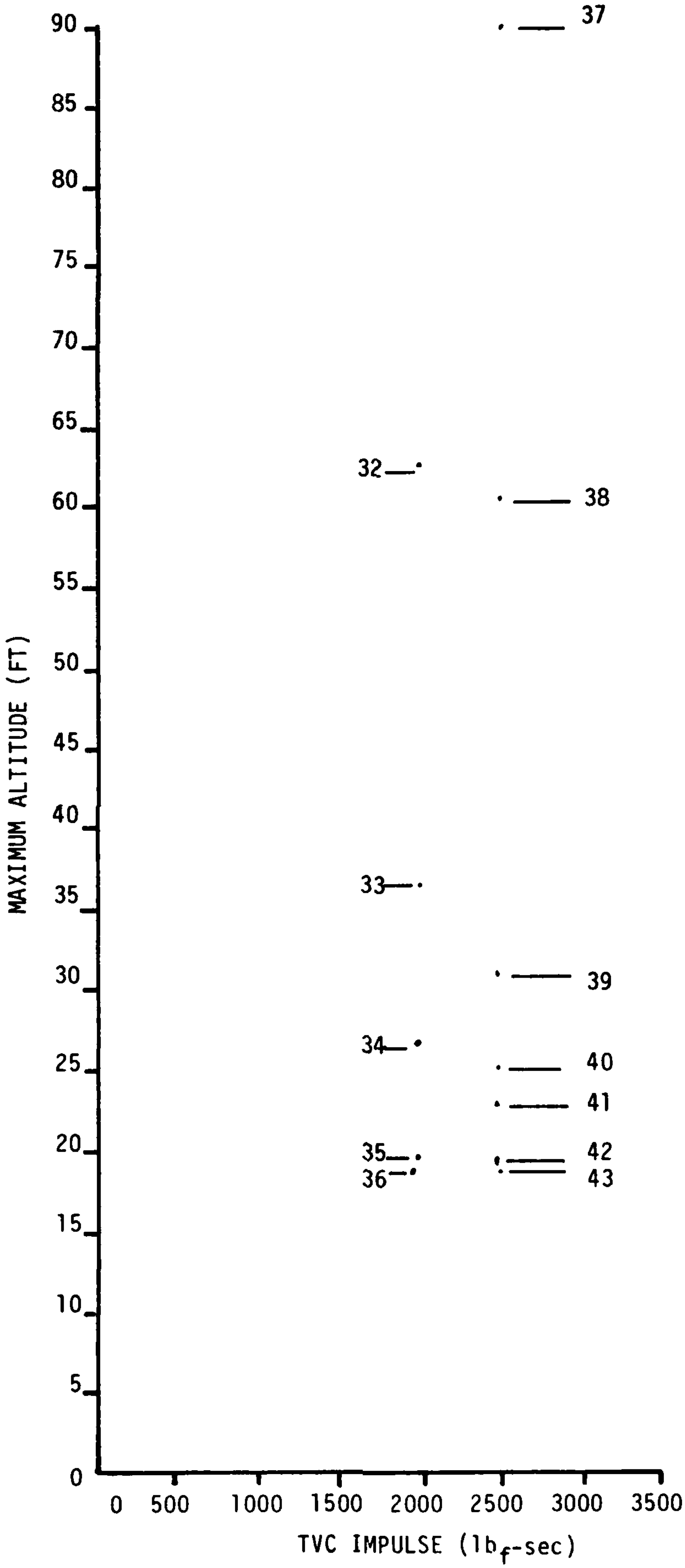


Figure 95. Model 2 Altitude vs Impulse

TABLE 1

USAF EJECTION EXPERIENCE
(5 YEAR INCREMENTS)
1 JAN 1949 - 31 DEC 1980
NON-COMBAT

	TOTAL EJECTIONS	SURVIVED NO.	SURVIVED %	FATAL NO.	FATAL %
1949-1953	349	268	77	81	23
1954-1958*	1257	1013	81	244	19
1956-1960*	1305	1098	84	207	16
1961-1965	905	754	83	151	17
1966-1970	845	714	85	131	15
1971-1975	449	368	82	81	18
1976-1980	361	270	75	91	25

* OVERLAP IN DATA

TABLE 2

EJECTION FATALITY CAUSES (1976-1980)

	1976	1977	1978	1979	1980	TOTAL
OUT OF ENVELOPE	8	12	12	19	15	66 (73%)
MISSING/DROWNED	2	2	1		1	6 (7%)
SYSTEM FAILURE	2		1	1		4 (4%)
STRUCK AIRCRAFT	2		1			3 (3%)
ESCAPE SYSTEM DAMAGE			1	2		3 (3%)
PARACHUTE ENTANGLEMENT					2	2 (2%)
BIRD STRIKE					1	1 (1%)
PARACHUTE OPENING SHOCK				1		1 (1%)
OTHER		2		2	1	5 (5%)
TOTAL	14	16	16	25	20	91

TABLE 3

COMPONENT WEIGHT, INERTIA & CENTER OF GRAVITY DATA

COMPONENT	WEIGHT (lbs)	Ixx (Slug-ft^2)	Iyy (Slug-ft^2)	Izz (Slug-ft^2)	Ixy (Slug-ft^2)	Ixz (Slug-ft^2)	Iyz (Slug-ft^2)	$\bar{x}$ (ft)	$\bar{y}$ (ft)	$\bar{z}$ (ft)
5th % Dummy	145.20	6.2640	6.7115	2.0413	-.0705	2.1431	0.4110	0.7403	.0136	-.8411
95th % Dummy	214.30	10.2578	10.4404	2.7071	-.1053	2.4229	0.5233	0.7186	-0.0116	-0.9446
Empty Seat	99.70	4.4350	4.6920	1.6210	0.1817	0.9866	0.0752	0.0379	0.0137	-0.4998
Rocket Propellant	5.60	0.1260	0.1260	0.0060	0.0000	0.0000	0.0000	-0.5100	0.0000	-1.5600
Drogue Chute	10.20	0.4587	0.1916	0.1457	0.1147	-0.0109	-0.0223	-0.4944	-0.2200	-0.7541
Recovery Parachute	21.95	0.0393	0.1090	0.1148	0.0569	-0.0126	-0.0408	-0.3080	-0.0077	-2.5460
Survival Kit-26 lb*	18.50	-0.0145	0.0319	-0.0844	-0.7514	-0.0633	0.1978	0.5914	-0.0122	0.4448
Survival Kit-40 lb*	34.35	0.1647	0.1007	-0.0996	-0.0563	0.0325	0.2123	0.6107	-0.0650	0.4071

* Empty Kit Weight Included In Empty Seat

Note: Moment of Inertia & Center of Gravity Data in Seat Axis System

TABLE 4

RECOVERY ALTITUDE ABOVE INITIATION POINT

AIRSPEED

	0	150	250(M1)	250(M2)	350	450
+10% Inertia	185	97	65	77	45	32
Normal	185	92	67	75	43	33
-10% Inertia	188	94	68	77	46	30

95th%, Heavy kit configuration.

TABLE 5

COMPUTER TEST CONDITIONS - A SERIES

RUN NO.	MODE	VELOCITY	CONDITIONS	ALT REQ	LAT DIS	FILL TIME
A001	2	450	5TH,MEDIUM KIT	-47	4	2.48
A002	2	450	5TH,HEAVY KIT	-49	5	2.47
A003	2	450	95TH,MEDIUM KIT	-32	1	2.47
A004	2	450	95TH,HEAVY KIT	-33	1	2.46
A005	2	450	95TH,HEAVY KIT,30 DEG DIVE	437	2	2.46
A006	2	350	" , " " , " " "	357	2	2.50
A007	2	250	" , " " , " " "	258	12	2.54
A008	2	450	" , " " ,60 " "	777	1	2.44
A009	2	350	" , " " , " " "	666	2	2.49
A010	2	250	" , " " , " " "	532	11	2.53
A011	2	450	" , " " ,90 " "	912	1	2.44
A012	2	350	" , " " , " " "	805	2	2.50
A013	2	250	" , " " , " " "	674	12	2.52
A014	1	250	" , " " , " " "	486	8	1.82
A015	1	150	" , " " , " " "	353	14	1.94
A016	1	150	" , " " ,60 " "	255	13	1.95
A017	1	250	" , " " , " " "	383	8	1.83
A018	1	250	" , " " ,30 " "	181	8	1.83
A019	1	150	" , " " , " " "	94	13	1.96
A020	2	250	5TH,MEDIUM KIT	-94	13	2.60
A021	2	275	" " "	-82	6	2.58
A022	2	300	" " "	-73	3	2.57
A023	2	325	" " "	-69	1	2.56
A024	2	350	" " "	-60	1	2.55
A025	2	250	95TH,HEAVY KIT	-75	11	2.58
A026	2	275	" " "	-70	4	2.56
A027	2	300	" " "	-61	3	2.55
A028	2	325	" " "	-52	2	2.53
A029	2	350	" " "	-43	2	2.52
A030	1	150	" " "	-92	13	1.97

TABLE 6

COMPUTER TEST CONDITIONS - R SERIES

RUN NO.	MODE	VELOCITY	CONDITIONS	ALT REQ	LAT DIS	FILL TIME
R001	2	250	95TH,HEAVY KIT,30 DEG ROLL	-75	46	2.55
R002	2	250	" , " " ,60 " "	-52	94	2.57
R003	2	250	" , " " ,90 " "	4	135	2.57
R004	2	250	" , " " ,120 " "	80	136	2.56
R005	2	250	" , " " ,150 " "	145	90	2.53
R006	2	250	" , " " ,180 " "	175	12	2.53
R007	2	250	5TH,MEDIUM KIT,30 " "	-73	69	2.59
R008	2	250	" , " " ,60 " "	-36	110	2.60
R009	2	250	" , " " ,90 " "	21	148	2.59
R010	2	250	" , " " ,120 " "	102	115	2.58
R011	2	250	" , " " ,150 " "	155	64	2.57
R012	2	250	" , " " ,180 " "	175	11	2.57
R013	1	250	95TH,HEAVY KIT	-67	8	1.84
R014	1	250	5TH,MEDIUM KIT	-71	1	1.81
R015	1	1	" , " "	-221	22	2.52
R016	1	1	" , " " ,30 DEG ROLL	-184	131	2.52
R017	1	1	" , " " ,60 " "	-101	213	2.53
R018	1	1	" , " " ,90 " "	0	247	2.50
R019	1	1	" , " " ,120 " "	133	213	2.23
R020	1	1	" , " " ,150 " "	248	118	2.13
R021	1	1	" , " " ,180 " "	257	26	2.15
R022	1	1	95TH HEAVY KIT	-185	72	5.09
R023	1	1	" " " ,30 DEG ROLL	194	182	9.50
R024	1	1	" " " ,60 " "	-40	252	5.20
R025	1	1	" " " ,90 " "	49	272	3.95
R026	1	1	" " " ,120 " "	166	248	3.45
R027	1	1	" " " ,150 " "	281	186	3.40
R028	1	1	" " " ,180 " "	275	43	2.56

AD-A161 052 ENHANCED EJECTION SEAT PERFORMANCE WITH VECTORED THRUST 2/2
CAPABILITY(U) AIR FORCE WRIGHT AERONAUTICAL LABS
WRIGHT-PATTERSON AFB OH L A JINES ET AL AUG 85
UNCLASSIFIED AFWAL-TR-84-3026 F/G 1/3 NL

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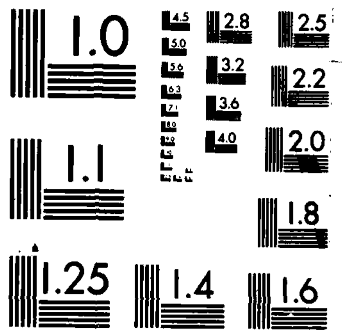

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

TABLE 7

COMPUTER TEST CONDITIONS - D SERIES

RUN NO.	MODE	VELOCITY	CONDITIONS	ALT REQ	LAT DIS	FILL TIME
D001	1	250	95TH,HEAVY KIT, 2000 FPM SINK RATE	-30	8	1.84
D002	1	250	" , " " , 4000 " " "	8	8	1.84
D003	1	250	" , " " , 6000 " " "	46	8	1.84
D004	1	250	" , " " , 8000 " " "	84	8	1.83
D005	1	250	" , " " ,10000 " " "	124	8	1.83
D006	2	250	" , " " , 2000 " " "	-26	9	2.59
D007	2	250	" , " " , 4000 " " "	23	8	2.58
D008	2	250	" , " " , 6000 " " "	70	9	2.57
D009	2	250	" , " " , 8000 " " "	121	9	2.57
D010	2	250	" , " " ,10000 " " "	171	9	2.57

TABLE 8

COMPUTER TEST CONDITIONS - S SERIES

RUN NO.	MODE	VELOCITY	CONDITIONS	ALT REQ	LAT DIS	FILL TIME
S001	1	220	5TH,MEDIUM KIT,135 DEG ROLL	87	70	1.82
S002	1	220	" " " , " " " ,30 DEG DIVE	258	67	1.82
S003	1	220	" " " ,180 " " , " " "	313	2	1.81
S004	1	300	" " "	-56	0	1.77
S005	1	325	" " "	-54	0	1.76
S006	1	400	" " "	-45	2	1.75
S007	1	300	35TH,HEAVY KIT	-47	5	1.80
S008	1	325	" , " "	-44	4	1.78
S009	1	400	" , " "	-47	5	1.77
S010	1	275	" , " "	-57	7	1.82
S011	1	275	5TH,MEDIUM KIT	-62	0	1.79
S012	1	250	" " " ,135 DEG ROLL	83	67	1.79
S013	1	250	" " " , " " " ,30 DEG DIVE ..	275	64	1.79
S014	1	250	" " " , " " " ,60 " " ..	406	63	1.79
S015	1	250	" " " , " " " ,90 " " ..	410	60	1.79
S016	2	250	" " " , " " "	129	77	2.57
S017	2	250	" " " , " " " ,30 DEG DIVE ..	385	90	2.56
S018	2	250	" " " , " " " ,60 " " ..	545	86	2.55
S019	2	250	" " " , " " " ,90 " " ..	570	83	2.56
S020	2	300	" " " , " " "	118	77	2.55
S021	2	300	" " " , " " " ,30 DEG DIVE ..	400	75	2.54
S022	2	300	" " " , " " " ,60 " " ..	584	73	2.54
S023	2	300	" " " , " " " ,90 " " ..	626	73	2.54
S024	2	350	" " " , " " " , ...	108	68	2.53
S025	2	350	" " " , " " " ,30 DEG DIVE ..	425	65	2.52
S026	2	350	" " " , " " " ,60 DEG DIVE ..	637	66	2.52
S027	2	350	" " " , " " " ,90 DEG DIVE ..	689	65	2.52

TABLE 9

ALTITUDE REQUIRED FOR RECOVERY FOR VARIOUS ROCKET THRUST LEVELS AT 200 KEAS

ROCKET THRUST LEVEL AND DURATION

Dive Angle (Deg)	ACES II Rocket Catapult	5000 # 0.4 Sec	5000 # 0.8 Sec	5000 # 1.2 Sec	5000 # 1.6 Sec	10,000 # 0.2 Sec	10,000 # 0.4 Sec	10,000 # 0.6 Sec	3000 0.66 Sec
0	-151(0)	-[illegible]39(0)	-442	-647(0)	-1000(0)	-221(0)	-370(0)	-503(0)	-258(0)
15	-13(18)	-111(17)	-332(17)	-519(17)	-727(17)	-113(15)	-285(16)	-420(15)	-105(19)
30	99	32(51)	-204(51)	-400(51)	-593(0)	18(41)	-199(41)	-343(41)	56 (63)
45	200	152	-93(92)	-297(92)	-476(91)	125	70	-276(70)	188
60	273	253	113(130)	-212(130)	-380(130)	210	95	-223(95)	298
75	331	308	359	-146(158)	-310(158)	273	290	-176(113)	355
90	349	331	319	-102(168)	-273(168)	297	203	-140(120)	380

NOTES:

( ) ALITITUDE AT LOW POINT IN TRAJECTORY

NEGATIVE NUMBER INDICATES ALTITUDE AT RECOVERY ABOVE INITIATION POINT

RECOVERY PARACHUTE INITIATED AT ROCKET BURNOUT

TABLE 10

ALTITUDE REQUIRED FOR RECOVERY FOR VARIOUS ROCKET THRUST LEVELS AT 450 KEAS

ROCKET THRUST LEVEL AND DURATION

Dive Angle	ACES II ROCKET CATAPULT	5000 # 0.4 Sec	5000 # 0.8 Sec	5000 # 1.2 Sec	5000 # 1.6 Sec	10,000 # 0.2 Sec	10,000 # 0.4 Sec	10,000 # 0.6 Sec	3000 # 0.66 Sec
0	-52(0)	-111(0)	-237(0)	-313(0)	-375(0)	-129(0)	-280(0)	-387(0)	-102(0)
15	164	114	-9(68)	-105(68)	-175(68)	107	-29(53)	-166(53)	122
30	360	315	206	98(193)	17(193)	312	181	43(141)	324
45	542	501	404	290(333)	192(333)	495	380	252	511
60	701	668	592	486	345(469)	666	564	441	677
75	796	769	680	676	447(561)	773	690	575	774
90	785	758	713	691	686	760	681	600	766

NOTES:

( ) ALTITUDE AT LOW POINT IN TRAJECTORY.

NEGATIVE NUMBER INDICATES ALTITUDE AT ROCOVERY ABOVE INITIATION POINT.

TABLE 11 THRUST VECTOR CONTROL ANALYSIS DATA

CASE NO.	INPUT: TVC ROCKET THRUST (lbf) / TIME (sec)								TVC IMPULSE (lbf sec)	TVC BURNOUT TIME (sec)	OUTPUT MODEL 1 θ (DEGREES)	MODEL 1 MAXIMUM ALTITUDE TIME (sec)	MODEL 1 MAXIMUM ALTITUDE (ft)	MODEL 2 θ (DEGREES)	MODEL 2 MAXIMUM ALTITUDE TIME (sec)	MODEL 2 MAXIMUM ALTITUDE (ft)
Baseline	0 / 0	3425 / .001	3630 / .03	3400 / .14	3150 / .28	1000 / .31	0 / .35		1031.4	.566	17.65	.88	18.60	-14.1	1.22	24.78
1	0 / 0	2500 / .001	2500 / .100	2500 / .150	2500 / .200	2500 / .250	0 / .300	0 / .350	811.3	.566	24.13	.70	13.19	-15.9	1.02	17.76
2	0 / 0	5000 / .001	5000 / .100	5000 / .150	5000 / .200	5000 / .250	5000 / .300	0 / .350	1622.5	.566	14.09	1.36	34.55	- 4.6	1.78	47.62
3	0 / 0	7500 / .001	7500 / .100	7500 / .150	7500 / .200	7500 / .250	7500 / .300	0 / .350	2433.8	.566	19.22	2.42	123.28	13.9	2.28	104.38
4	0 / 0	10000 / .001	10000 / .100	10000 / .150	10000 / .200	10000 / .250	10000 / .300	0 / .350	3245.0	.566	36.04	3.32	230.08	36.0	3.68	207.58
5	0 / 0	5000 / .001	5000 / .100	5000 / .150	2500 / .200	2500 / .250	2500 / .300	0 / .350	1247.5	.566	7.88	.80	22.09	-23.4	2.52	77.08
6	0 / 0	7500 / .001	7500 / .100	7500 / .150	2500 / .200	2500 / .250	2500 / .300	0 / .350	1746.3	.566	8.27	1.52	43.28	-20.4	1.48	56 55
7	0 / 0	10000 / .001	10000 / .100	10000 / .150	2500 / .200	2500 / .250	2500 / .300	0 / .350	2182.5	.566	22.71	2.32	91.77	- 7.7	2.48	89.83
8	0 / 0	7500 / .001	7500 / .100	7500 / .150	5000 / .200	5000 / .250	5000 / .300	0 / .350	1933.8	.566	14.72	2.26	78.84	2.1	1.86	71.07
9	0 / 0	10000 / .001	10000 / .100	10000 / .150	5000 / .200	5000 / .250	5000 / .300	0 / .350	2620.0	.566	28.89	2.46	129.68	13.5	2.82	122.98
10	0 / 0	10000 / .001	10000 / .100	10000 / .150	7500 / .200	7500 / .250	7500 / .300	0 / .350	3057.5	.566	32.89	2.86	172.38	25.0	3.26	163.58
11	0 / 0	2500 / .001	2500 / .100	5000 / .150	5000 / .200	2500 / .250	2500 / .300	0 / .350	1061.3	.566	20.17	.88	20.30	- 6.2	1.00	18.97
12	0 / 0	2500 / .001	2500 / .100	7500 / .150	7500 / .200	2500 / .250	2500 / .300	0 / .350	1248.8	.566	17.84	.90	28.37	1.9	1.66	29.08
13	0 / 0	2500 / .001	2500 / .100	10000 / .150	10000 / .200	2500 / .250	2500 / .300	0 / .350	1561.3	.566	16.42	.94	36.85	-.4	1.64	36.86
14	0 / 0	5000 / .001	5000 / .100	7500 / .150	7500 / .200	2500 / .250	2500 / .300	0 / .350	1622.5	.566	6.95	2.34	64.47	-12.4	2.71	97.01
15	0 / 0	5000 / .001	5000 / .100	10000 / .150	10000 / .200	2500 / .250	2500 / .300	0 / .350	1872.5	.565	6.09	2.60	76.43	-12.4	2.40	65.82
16	0 / 0	7500 / .001	7500 / .100	10000 / .150	10000 / .200	2500 / .250	2500 / .300	0 / .350	2183.8	.566	10.71	2.42	100.48	- 4.3	2.50	93.17
17	0 / 0	2857 / .3999	2857 / .3999	0 / .350					1000.0	.566	22.9	.86	17.1	-11.6	.96	18.26
18	0 / 0	4287 / .0001	4287 / .3499	0 / .3500					1500.0	.566	16.7	.94	29.5	- 4.8	1.20	28.85
19	0 / 0	5714 / .0001	5714 / .3499	0 / .3500					2000.0	.566	15.2	1.02	39.2	0.7	1.84	55.31
20	0 / 0	7143 / .0001	7143 / .3499	0 / .3500					2500.0	.566	18.8	2.86	126.6	12.6	2.26	105.08
21	0 / 0	8571 / .0001	8571 / .3499	0 / .3500					3000.0	.566	26.7	3.10	181.2	23.6	3.16	151.68

TABLE 11 (Concluded)

CASE NO.	INPUT: TVC ROCKET THRUST (lbf) / TIME (sec)								TVC IMPULSE (lbf sec)	TVC BURNOUT TIME (sec)	OUTPUT: MODEL 1 θ (DEGREES)	MODEL 1 MAXIMUM ALTITUDE TIME (sec)	MODEL 1 MAXIMUM ALTITUDE (ft)	MODEL 2 θ (DEGREES)	MODEL 2 MAXIMUM ALTITUDE TIME (sec)	MODEL 2 MAXIMUM ALTITUDE (ft)
22	0 / 0	5714 / .175	0 / .350						1000.0	.566	30.5	.66	9.3	-4.7	.94	17.4
23	0 / 0	8571 / .175	0 / .350						1500.0	.566	17.2	.94	35.5	.4	1.64	36.74
24	0 / 0	11429 / .175	0 / .350						2000.0	.566	14.0	2.72	115.2	-2.4	2.12	71.97
25	0 / 0	14286 / .175	0 / .350						2500.0	.566	11.2	2.54	107.1	1.2	2.68	126.88
25	0 / 0	17143 / .175	0 / .350						3000.0	.566	13.7	2.96	190.8	6.7	3.42	212.68
27	0 / 0	1500 / .0001	4214 / .175	1500 / .3499	0 / .3500				1000.0	.566	22.7	.86	18.3	-8.4	.96	17.68
28	0 / 0	1500 / .0001	7071 / .175	1500 / .3499	0 / .3500				1500.0	.566	16.9	.92	33.4	- .2	1.68	34.76
29	0 / 0	1500 / .0001	9929 / .175	1500 / .3999	0 / .350				2000.0	.566	14.0	4.00	170.1	-2.0	2.78	82.26
30	0 / 0	1500 / .0001	12786 / .175	1500 / .3999	0 / .350				2500.0	.566	12.6	2.70	112.8	3.2	2.70	125.38
31	0 / 0	1500 / .0001	15693 / .175	1500 / .3499	0 / .350				3000.0	.566	16.1	2.94	190.4	9.6	3.52	202.48
32	0 / 0	1500 / .0001	6500 / .250	1500 / .9999	0 / .500				2000.0	.716	8.4	1.86	47.93	34.3	2.14	62.59
33	0 / 0	1500 / .0001	3833 / .375	1500 / .7499	0 / .750				2000.0	.966	-49.0	.90	15.07	33.8	1.90	36.80
34	0 / 0	1500 / .0001	2500 / .500	1500 / .9999	0 / 1.0				2000.0	1.216	-44.3	.68	10.97	19.5	2.36	26.98
35	0 / 0	1500 / .0001	1700 / .625	1500 / 1.249	0 / 1.250				2000.0	1.466	-57.8	.66	9.87	7.9	1.08	19.66
36	0 / 0	1500 / .0001	1507 / .665	1500 / 1.329	0 / 1.33				2000.0	1.549	-19.5	.66	9.69	7.1	1.10	19.60
37	0 / 0	1500 / .0001	8500 / .250	1500 / .4999	0 / .5				2500.0	.716	20.5	1.98	80.60	32.9	2.54	90.02
38	0 / 0	1500 / .0001	5167 / .375	1500 / .7499	0 / .75				2500.0	.966	-28.2	1.10	21.78	35.5	2.50	60.76
39	0 / 0	1500 / .0001	3500 / .500	1500 / .9999	0 / 1.0				2500.0	1.216	52.8	.68	12.35	19.9	1.78	31.11
40	0 / 0	1500 / .0001	2500 / .625	1500 / 1.249	0 / 1.25				2500.0	1.466	64.4	.68	10.76	5.0	1.74	25.44
41	0 / 0	1500 / .0001	2260 / .665	1500 / 1.3299	0 / 1.33				2500.0	1.546	-56.3	.68	10.39	2.8	1.70	23.04
42	0 / 0	1500 / .0001	1833 / .75	1500 / 1.499	0 / 1.50				2500.0	1.716	6.2	.66	9.95	0.0	1.50	19.76
43	0 / 0	1500 / .0001	1625 / .80	1500 / 1.599	0 / 1.60				2500.0	1.816	20.0	.66	9.77	-1.1	1.10	19.63

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